European Sustainable Phosphorus Platform

SCOPE NEWSLETTER

October 2017 n° 125

Innovation

BIG P Conference, Old Trafford, Manchester

Challenges of tightening phosphorus discharge limits for big and small sewage works: technologies, economic costs, environmental costs, biosolids.

SYMPHOS: Phosphorus industry & phosphorus use innovation

Summary of the 4th International Symposium on Innovation and Technology in the Phosphate Industry.

US Phosphorus RCN

US P-RCN (Research Coordination Network) final meeting shows many publications and some outstanding questions.

North America Phosphorus Forum

The Sustainable Phosphorus Alliance (North America) second stakeholder Forum, Washington DC, looked at phosphorus management today and tomorrow.

Newtrient's manure management technology catalogue

US dairy company Newtrient launches online selection tool for manure nutrient recycling technologies and suppliers.

Recycled fertilisers

UK assessment of targeted phosphorus fertilisation

A major UK project has studied possible strategies to improve phosphate fertiliser use by arable crops and reduce environmental losses.

Attitudes to innovative fertilisers

A survey of stakeholders and farmers in Germany shows difficulties of uptake of fertiliser eco-innovations.

See agenda at the bottom for: **SAVE THE DATE 3rd European Sustainable Phosphorus Conference and ManuREsource 2017, 27-28 Nov. incl. ESPP policy round table processed manure in Nitrates Directive and 1-to-1 meetings with Newtrient - catalogue of manure processing technologies.**

Health and safety

Ecotoxicity of fertilisers & potassium monophosphate

Potassium, nitrogen and phosphate fertilisers and relevant mineral salts were tested for ecotoxicity on aquatic snails and fish.

New book on phosphorus food science

17 chapters current knowledge on P metabolism, P in food, P and health and nutrient interactions.

Ecotoxicity of recycled phosphate products

Contaminants analysed and ecotoxicity tested for 3 struvites, 5 thermal recovered phosphates, and leachates, suggesting low risk to the environment from use in agriculture.

Circular economy and recycling

France conference on phosphorus recycling in agriculture

First ever national meeting on recycled phosphorus in agriculture discusses recycled nutrient products quality, policy, legislation and circular economy.

Resource efficiency in practice: improving farm nutrient management

EU funded, 8 regions project to identify optimal nutrient actions and to inform farmers and decision makers.

World Circular Economy Forum (WCEF)

First WCEF, Helsinki, 5-7 June 2017, with 1 500 participants, showed considerable international interest in the circular economy, incl. links to the bio-based economy.

All Ireland phosphorus workshop

Phosphorus Sustainability and Microbial Resources meetings, Belfast, June 2017 identify challenges for Ireland and brings together latest research.

Phosphorus recovery & recycling in Japan

Site visits: Gifu alkaline sludge ash leaching, Kubota sludge furnace.

The partners of the European Sustainable Phosphorus Platform

Innovation

BIG P Conference, Old Trafford, Manchester

Aqua Enviro's "Big P" Conference, Manchester United Old Trafford Stadium, UK, 4-5 July 2017, brought together some 200 experts from the UK and European water industry, technology suppliers and regulators. Discussion centred on technologies to achieve increasingly stringent phosphorus discharge consents to address EU Water Framework Directive obligations, down to 0.5 or even 0.05, in both larger and small sewage works. Impacts on economic costs, energy consumption, sludge production and recycling were raised, as well as possible flexible permitting to optimise implementation.

Simon Leaf, Environment Agency, explained the significance of phosphorus losses to water in the UK. Freshwater is estimated to have yearly economic value of nearly UK£ 40 billion (ONS Office of National Statistics) taking into account only public water supply, fisheries and recreation (not property value) and eutrophication detracts from these services. Through to 2018, the UK water industry will have **invested UK£ 2 billion in phosphorus removal**.

This has had **positive results** (e.g. East Anglia's rivers' phosphorus levels have fallen from 1 mgP/l in the 1990's to 0.2 today), but still over a quarter of rivers and lakes suffer from "very certain" eutrophication, and 50% of river water bodies show phosphorus levels too high for Water Framework Directive good ecological status.

Today around 2/3 of phosphorus loads to England's freshwaters are from sewage works, and around a quarter from agriculture although this varies greatly across catchments. **Phosphorus inputs to sewage works correspond to around ¾ of mineral fertiliser use, so a potential resource for recycling**.

Policy developments

For Simon Leaf, as well as a big focus on further reducing phosphorus discharges from sewage treatment works and agricultural sources, policy should **continue to consider source control**. The bans on phosphates in domestic laundry and dishwasher detergents have led to a c. 15% reduction in sewage works inflow phosphorus since the 1990's. Leakage of drinking water from piping represents around ¼ of WWTP phosphorus emissions in the Thames catchment, because phosphates are dosed to drinking water to reduce lead solvency. Tap water dosing also contributes about 6% of P in sewage. **Thinking more radically dietary choices** may also need to be questioned, because food and drink are responsible for around 60% of phosphorus entering sewage works. Policies can be made more efficient by developing nutrient emissions trading, flexible catchment-based permitting and should also take into account objectives of phosphorus stewardship, so considering how to make best use of P as a non-renewable resource whilst also protecting the environment. These objectives will require the development of phosphorus flow analyses at the water company and catchment levels. Innovation in sewage treatment methods can play a major role.

Chris Thornton, European Sustainable Phosphorus Platform (ESPP), presented developments in **European policy relevant to nutrient management**, from the 'command and control' EU Urban Waste Water and Nitrates Directives (1991), which are still key drivers for waste water treatment, through the ambitious and holistic EU Water Framework Directive (2000) to more recent policies for the nutrient stewardship. He underlined the recognition of nutrients as a key sector for the EU's Circular Economy objectives, with phosphate rock now on the EU Critical Raw Materials List, ammonia recovery driven by the National Emissions Ceilings Directive, and the current development of the EU revised Fertilisers Regulation, which will open markets for recycled nutrient products and for nutrient recycling technologies.

At the same time, **regulatory requirements for phosphorus recycling** are being implemented by Germany (see ESPP eNews *n°12*) and Switzerland (SCOPE Newsletter *n°105*), and obligatory actions also by HELCOM (9 countries, see ESPP eNews *n°9*).

He presented a number of **success stories where phosphorus is today already being recycled in tens of thousands of tonnes of different fertiliser products**, including the REVAQ sewage quality scheme to ensure confidence in use of sewage biosolids in agriculture, production of organic fertilisers from wastes and by-products, recycling of chicken litter combustion ash and meat and bone meal ash as fertilisers, biogas and fertiliser from food wastes, struvite recovery in sewage works and use as a fast-access starter fertiliser for maize, and recovery of phosphorus for industrial applications from sewage sludge incineration ash.

Pete Vale, Severn Trent Water, outlined the phosphorus removal challenge faced by the water industry. Phosphorus is still today the most common (non morphological) cause of EU Water Framework Directive quality failure. Over half of river water bodies and three quarters of lakes exceed the phosphorus level for "good environmental status". And this despite 2 billion UK£ investment (including current AMP - Asset Management Plan - Programme). **Phosphorus discharge consents are therefore expected to be reduced to 0.1 mgP/l, even for small sewage works**.

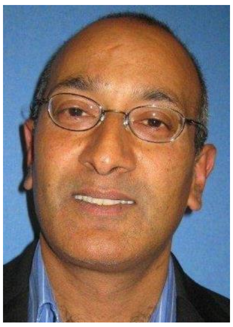
Mr Vale presented the **UK national phosphorus removal technology trials programme** underway (part of CIP2, see ESPP eNews *n°7*) organised by UK WIR, the Environment Agency and all the UK water companies. This is assessing seven "novel" technologies which are known to be able to achieve 0.1 mgP/l but are not yet implemented in the UK: (**Blue PRO or similar modified COUF, Mecana, Fuzzy Filter, Co-Mag/Bio-Mag, Adsorption Media, FilterClear, Dynasand Oxy**). Other studies include lab-scale testing of new innovative technologies and optimising existing sewage works configurations, such as trickling filters.

The future means very low phosphorus discharge consents

Most approaches to achieving very low P discharge involve **adding additional treatment steps downstream of existing nutrient removal process, using filtration or another process to remove suspended matter**, which includes phosphorus reacted with P-removal chemicals. Without suspended solids removal down to very low levels, reacted phosphorus is lost in discharge. Such solids removal processes being tested include reedbeds, dissolved air flotation, electro-coagulation, and development of granular sludge.

A difficulty is to achieve reliable low P discharge levels all the time, and it will be important to take this into account in permitting to allow compensation of occasional process failures against periods of over-performance.

Mr Vale noted that **processes using chemical P-removal raise concerns about supply security of iron salts** (imported into the UK, no national supplier), **risk of price increases of these iron salts** with increasing demand, and **iron discharge limits**.



Narinder Sunner, MWH Ltd, summarised experience from 16 municipal waste water treatment plants in the USA which have very low discharge consents (0.05 mgP/l average). Achieving such phosphorus discharge limits implies suspended solids discharge below 1 mgSS/l, that is drinking water standards. **Technologies used include membranes, sand filters, cloth pile filters, ballasted filters**.

Mr Sunner underlined that the US experience shows that operating such systems requires **high levels of maintenance by highly qualified personnel**, based onsite, with appropriate training programmes, as well as high levels of investment in monitoring equipment and automation. This is contrary to UK trends, where personnel onsite has been cut by half since 1990, skill loss from the water industry to other sectors, and a failure to finance capital maintenance.

Capital investments can be economised by improving reliability of installations (reduce the need for reserve equipment) but for the future, **choices may have to be made between increased automation or increased personnel and upskilling**.

Solids removal to achieve low phosphorus

Lynn Smith, Yorkshire Water (photo) and **Karen Young, Arup**, presented the **lessons learnt from their involvement in three of the CIP Low Phosphorous Trials** in terms of design preparation, optimisation of the ferric doses, online instrumentation, effect of dosing on the works mass balance and ferric solids generation and implications for design of solids capture units.

Upfront jar tests were used to calculate initial ferric doses to stage 1 (preliminary settling tank inlet) to target a total P concentration of 1mg/l in the feed to the stage 2 dose. Temporary ferric dosing was set up to adapt the site to ferric and evaluate the effect of the proposed stage 1 dose. Stage 1 dose control using a pre-determined diurnal P load profile proved effective for the trial sites which were mainly gravity flow and low levels of trade waste. However, stage 2 ferric dose control using an **online orthophosphate instrument proved unreliable** due to instrumentation maintenance demands, resulting in a change to flow proportional control which was used successfully during the trial. Monitoring of backwash composition after solids capture highlighted the level of iron return to the inlet, which in some trials allowed for a reduction in stage 1 dose. **Seasonal changes in works performance and final effluent quality** showed that jar testing needs to be carried out on a regular basis to confirm the correct stage 2 dosing to achieve both low total P and low residual iron in the filtered effluent. Accumulation of iron in feed and filtered pipework led to excessive biofilm growth and accumulation across all trials, emphasising the **need for a good monitoring and maintenance regime across the plant**. A comparison of the design solids load and actual solids loading onto the solids capture units highlighted the **importance of understanding the site conditions and performance and the impact of ferric on solids generation prior to confirming the solids capture design**. Overall, this means that significant preparation time is needed to enable monitoring, evaluation and adjustments where such tight P consents are set.

Achieving very low phosphorus discharges – theory and reality

To summarise the different presentations below, ESPP notes that **there are a range of technologies today available to achieve very low phosphorus final discharge from sewage works (< 0.1 mg total P/l).** These have been demonstrated to achieve this in real operating conditions, but that should not be interpreted as meaning they can simply be plugged onto a sewage works discharge and will then consistently deliver the target phosphorus limit. Sewage works are all different, and all have variable flows and organic loads, and this may lead to operating challenges, including possible fouling of systems or monitoring and control equipment. Particularly for systems based on ferric dosing and final removal of particulates (including removal to low levels of precipitated iron phosphate), ferric dosing is complex to adjust and control, in order to achieve phosphorus removal without inducing operational dysfunction or excess iron discharge. **For all technologies, attentive design integration of the technology into the sewage works operating parameters is essential to optimise performance and minimise risk of operating problems or fouling, and appropriate levels of maintenance and operational surveillance must be anticipated**, all of which implies further costs, additional to the technology and its direct operating costs. Additional costs can also be expected from the need for contingency installations/capacity, increased sewage sludge production, increased chemical storage and tanker movements for ferric supply, and the need for increased onsite staffing.

Martin Butterfield, Hach UK, presented **challenges related to iron dosing to achieve low discharge standards.** Dosing can be optimised by controlling based on both discharge P levels and inflow parameters (flow, phosphorus level). Measuring ortho-phoshorus can be a challenge in practice: continuous monitoring equipment exists, but requires maintenance (e.g. cleaning flow filters, especially when monitoring inflow sewage).

Alkalinity consumption is an important consideration. Dosing of acidic metal salts to achieve 0.5 mgP/l discharge consent or lower could consume nearly all alkalinity remaining after denitrification, whereas nitrifying bacteria activity can be reduced by 25% if pH falls from 8 to 7. Buffered iron salts can address this problem, as could using de-nitrification to recover alkalinity by internal recirculation.

Estela Alvarez Moreta (photo), **Thames Water**, **Lynn Smith, Yorkshire Water**, and **Lewis O'Brien, Eliquo Hydrok**, presented testing of the Mecana solids capture technology by three water companies (Yorkshire Water, Thames Water, South West Water) across four wastewater treatment sites to evaluate the feasibility of achieving an effluent consent of <0.1mg/l total P.

Lewis O'Brien gave a brief overview of the **Mecana** unit, which comprises discs covered in deep pile cloth, vertically mounted onto a centre tube and installed within a tank. When the cloth becomes blocked with solids, backwashing is initiated through a vacuum pump system. Standard and microfibre cloths are used for different levels of solids filtration.

Estela Alvarez Moreta and Lynn Smith presented the findings of the trials from their water companies, and South West Water, which covered different size sites (14 to 269 l/s) and included both filter works and ASP (activated sludge process)/oxidation ditch treatment processes. Alum or ferric was dosed upstream of primary settling tanks and at the final effluent prior to the Mecana unit. Results from 12 months sampling showed that through optimising ferric dose rate, managing upstream processes and when all dosing equipment and instrumentation was operating correctly, a Mecana effluent quality of 0.1mg/l TP could be achieved. However, due to **issues of ferric dose reliability and control**, seasonal changes in final effluent quality and instrument maintenance requirements, the 12 month average value was 0.12 to 0.23mg/l TP. The oxidation ditch and ASP sites achieved the best results due to the good final effluent quality and in one trial a two-stage Mecana was used (standard + microfibre) which improved solids capture. Key findings included a **higher than expected solids generation rate due to ferric dosing, the different limiting solids loading rate for each site and between seasons, and the maintenance demands of online instruments** that will imply increased operational input.

Lynn Smith, Yorkshire Water, Karen Young, ARUP and Caroline Huo (photo), **BlueWater Bio**, presented the **FilterClear** plant tested by Yorkshire Water at Bolsover WWTP with the objective of achieving 0.1 mg total P/l discharge. **FilterClear** is a down-flow 4-media (anthracite, silica, alumina and magnetite) filtration system, delivered as a ready-to-install package plant, with capacity to treat a wide range of flow from 100 m^3/d to over 100 MLD. **The trial samples showed that the FilterClear unit achieved 0.1 mg total P/l effluent quality over the first 5 months of operation, and at times down to 0.06 mg/l total P in some operating conditions**.

The trial highlighted **a number of operating issues which are common to any tertiary phosphorus removal system**, including accurate selection of design parameters, operation and on site conditions and difficulties of dealing with high flow periods. An accurate estimation of the solids generation rate from the addition of ferric dosing is essential to inform appropriate sizing for the filter. Operational parameters include correct design, operation and maintenance of chemical dosing control, online instrumentation, and feed flow and backwash control. Good flocculation is important for any phosphorus removal system to ensure good performance and a low iron residual, yet the necessary dose rate may change over time so good monitoring and jar testing are important. **Online monitors and parts of the inlet and outlet distribution system are prone to fouling by biofilms and require regular cleaning**.

It was noted that as ferric dosing rates increase, more flocculated solids are formed, **increasing the load on the filter, the frequency of backwashing and the total sludge generated from the works**.

Jim Goodwin, Evoqua presented the **CoMag** ballasted clarification system which uses magnetite (Fe_3O_4) dosing to increase specific gravity of flocs and so improve solids settling. Magnetite is an inert, cheap, naturally occurring mineral. Additionally, 99% of the magnetite dosed can be retrieved after floc settling for recycling in the treatment system. **A number of full-scale installations are operating worldwide since 2007, and six full-scale pilot trials are being operated in the UK**.

He summarised experience at the Concord WWTP, Massachusetts. This 5 million l/day plant operates trickling filter biological treatment plus secondary settling humus tanks. Tertiary CoMag treatment has shown that the current discharge consent of 0.2 mgP/l, but also a possible future consent of 0.05 mgP/l can be achieved with near zero magnetite loss (without needing a magnetic trap) and with no erosion of sludge recycle pumps. Various improvements to the CoMag process over the last 10 years were discussed. CoMag can be installed outside with only lagging and trace heating, using prefabricated HDPE tanks. Stop-start operation is possible for stormwater treatment. **The CoMag process has recently been selected for tertiary P removal at Finham, a 248 million litre/day plant near Coventry (Severn Trent Water).**

Cécile Bourdon, Suez International, presented the **Densadeg** high rate settling and **Greendaf** high rate flotation tertiary phosphorus precipitation and solids separation systems.

Densadeg uses **lamella settling tanks, with high performance in-tank mixing of coagulant (iron or aluminium) and polymer** (0.3-1.0 mg/l) to precipitate orthophosphates and remove suspended solids from sludge with up to 25 gDS/l, to achieve < 0.1 mgP/l. Over 200 installations are operational worldwide in industrial wastewater treatment, of which 30 are in sewage works tertiary treatment with capacities ranging from 7 to 200 MLD. Experience shows that stormwater flows can be treated to respect solids discharge consents by increasing polymer dosing.

Greendaf uses **bubble flotation** (pressure release from injection of pressurised water) and coagulant (iron or aluminium), polymer dosing is only needed for high suspended solids, with 4 installations now operating worldwide. Phosphorus levels of down to 0.1 mgP/l can be achieved in sludge of up to 15 gDS/l

Naiara Fonseca, Thames Water, presented UK **trials of constructed wetlands or reed beds with reactive media**, comprised of four reed beds treating 200 to 300 p.e. each. This was presented as an economic solution to achieve low phosphorus discharge consents in small sewage treatment works, as an alternative to dosing iron or aluminium salts followed by tertiary filtration, which implies potable water and chemical safety shower installation, chemical tanks, increased maintenance and energy requirements and increased sludge production.

Reed beds tested using **Basic Oxygen Furnace (BOF) steel slag** showed issues with interference with calcium carbonate during the trial and release of vanadium; and iron, manganese and aluminium to a lesser extent.

Reed beds with **apatite (ground phosphate rock mixed with a binder)** supplied by **Timab (Roullier)** achieved consistently < 0.2 mg TP/L with an estimated bed lifetime of 12 years. The exhausted apatite might be used as a phosphorus rich soil amendment at end-of-life. The reed bed can be installed as a tertiary treatment process, preceded by a solids removal step increasing apatite bed lifetime. This is a proven technology with 20 sewage treatment works operating apatite-based reed beds in France, but it is the first trial carried out in the UK.

Gregory Möller, University of Idaho, presented **N-E-W Tech (nutrient-energy-water),** their third-generation **reactive filtration system for phosphorus, solids, pathogen, and priority substance removal** from wastewater. Their **Team BlueXGreen** entry of reactive filtration was named winner of the first phase of stage 1 (concept) of the Barley Prize (selected from the first batch of entries). The overall winner of stage 1 was **WETSUS NaFRad** (see ESPP eNews *n°9*). Stage 1 of the prize (phases 1, 2 and 3) had a total of 75 entries. Stage 2 (lab testing) entries closed 15th July.

N-E-W Tech includes a developing range of reactive filtration solutions (reactive media in an upflow moving sand bed filter with continuous backwash, using iron salts (e.g. **BluePro**, see below), ozone and biochar. Two first generations of the technology (ferric iron, and ferric/ferrous iron with ozone for catalytic oxidation) are **operating commercially** (Nexom/Blue Water Technologies, Evergreen Water Solutions, UK) with installations up to >50 million litres/day, achieving down to 0.012 mgP/ discharge in operation and 99.6% TP removals. The third generation now being developed uses iron, ozone (oxidation) and biomass biochars to **remove phosphorus and recover it as phosphorus-loaded biochar which can be valorised as a fertiliser** and carbon-negative soil amendment (1.7%P, 0.8%N). A lorry-transportable pilot plant is operational.

Victoria Wilson, Dwr Cymru Welsh Water, presented the UKWIR testing of the **BluePro** continuous backwash gravity sand filters at Anglian Water, Severn Trent and Dwr Cymru. In this patented system, **ferric sulphate forms a hydrous ferric oxide (HFO) coating on sand that efficiently adsorbs phosphorus**. The P-enriched coating is removed by the grinding motion of the moving sand bed, and then the HFO-adsorbed phosphate is removed from the sand in a patented "wash box", resulting in a dynamic co-precipitation and adsorption P-removal process. In these trials (> 1 year operation, 1 - 8 million l/day), phosphorus effluent levels of 0.5 - 1.3 mgP/l (95%ile) were achieved. Issues identified were **difficulty to adapt to flow changes, tendency to blockages and plugging and losses of filter media**.

Alan Weber, Neo Performance Materials, presented the **use of rare earth metals for phosphorus removal**. These elements form strong crystalline bonds with phosphorus, rather than the amorphous "flocs" from iron or aluminium. They react rapidly, giving a dense precipitate which is easily settled to achieve low P discharge levels. Full scale experience at over 40 trials using **Cerium** and **Lanthanum**, non-toxic rare earths, full-scale at Hartford (Wisconsin), achieving 0.075 mgP/l with 40% less sludge production that when achieving 1.0 mgP/l with iron dosing, and at Albion (Pennsylvania) achieved 0.5 mgP/l with significant improvement of belt filter press operation and sludge dewatering.

Ben Gersten, Cardiff University, presented **use of water treatment residuals as adsorbents** for phosphorus removal in sewage works. Nearly 200 000 t/y are generated in the UK from using iron or aluminium salts to remove colour, organics, turbidity etc. from drinking water. Small scale pilot trials have been carried out suggesting that 0.1 or 0.05 mgP/l can be achieved.

Paul Cooper, Veolia, presented the company's **Actiflo** solutions for tertiary finishing solids removal. This combines iron or aluminium salts for flocculation with polymer dosing and sand-ballasted lamella settling, enabling high operational velocities, reliable low phosphorus discharge levels <0.1mg/l and effective operation in variable flow, load or stop-start conditions. The **sand ballast improves floc settling and solids removal** resulting in efficient P removal to very low levels. The **Veolia MA Hydrocyclones** enable separation of sand from flocs and return to the process for re-use. Veolia have over 50 installations operational worldwide and over 20 years' experience in phosphorus removal applications. The key to performance is the quality of the enhanced floc formation, achieved by mixing the flocculant and **Actisand**™ within the patented turbo shroud prior to the lamella settling area.

Holistic approaches to sewage phosphorus removal

Mr Cooper underlines the **exponential resource cost of achieving lower phosphorus discharge consents**. Tests at Brunswick, USA, show that around 2 molar (to P) dosing of iron salts is needed to achieve 2.5 mgP/l discharge, 20 molar for 0.5 and over 60 molar for 0.1 mgP/l. UK trials showed that to reduce inlet 0.64 mgP/l to discharge 0.05 mgP/l, ferric at 8 – 10 mgFe/l and polymer at 1 mg/l were needed.

The considerable **economic and environmental costs of such chemical consumption and of installation investments and sludge disposal should be considered carefully by regulators** before fixing very low discharge consents for sewage works, and other approaches to reducing phosphorus loads should be considered, in particular losses from agriculture.

Patricia Arcenegui, Veolia, explained that the group is integrating phosphorus stewardship, by **developing P-recycling** as well as P-removal. Veolia already produces and sells soil conditioner produced from composted household green waste under the brand name **Pro-Grow**. Veolia is also developing a recycled fertiliser based on ashes from food industry by-products and other bio-wastes. The company has purchased a granulation and packaging factory in Scotland (Livingstone, near Edinburgh, capacity 20 000 t/y) which already produces a range of liming materials and micro-nutrient products for the horticultural and agricultural markets, with the **capacity of processing 6 000 to 20 000 t/year of ash**. The ashes are rich in phosphorus and potassium, so nitrogen is added to achieve a balanced nutrient product. After successful pot trials, market tests are now underway.

Edoardo Piano, ARUP, outlined the challenges to **maintaining the recycling of sewage biosolids in agriculture, which enables the valorisation not only of phosphorus, but also of nitrogen and other (micro)nutrients, as well as the return of carbon to soil**. In the UK, application is controlled by the Biosolids Assurance Scheme which ensures that phosphorus is not over-applied and that there are no risks from pathogens. Metal contaminants are progressively being reduced by source control, but the future challenge will be from organic contaminants such as PAH (poly aromatic hydrocarbons), brominated flame retardants and pharmaceuticals. UK WIR studies are underway into pharmaceuticals (see ESPP eNews *n°7*) and further investigation is needed to better understand impacts on soils and on crops, and the risk of losses to water from land-applied biosolids. Studies are also needed on micro-plastics.

Mr Piano notes that **lower phosphorus discharge consents will have important impacts on biosolids management**. Sewage sludges will contain higher phosphorus levels, so that application guidance may also need in the future to ensure that nitrogen application does not exceed crop needs. Transport costs will increase, as maybe twice the land surface will be required for application conform to phosphorus limits. Increased levels of iron salts in biosolids will lead to accumulation of iron in top soils (iron does not generally leach downwards), raising questions about phosphorus availability in the soil and its management. Iron levels may also lead to iron phosphate (vivianite) nuisance deposits in sewage works, and to reduced biogas production (higher levels of inerts in sludge).

Lydia O'Shea, Wessex Water, presented implementation of '**catchment permitting**' on the Bristol Avon with the Environment Agency, see SCOPE Newsletter *n°124*. The objective is to deliver phosphorus load reductions to the river at the least cost and with optimal environmental improvement of the different sections of the river. 24 WWTPs are concerned (with P-removal obligation). Each will have a specific discharge permit, with 'backstop' P limit (Urban Waste Water Treatment Directive limit), but also has a 'stretch' target. The **'stretch' targets** calculated together will achieve a total catchment reduction of 134 to 88 tP/year from WWTPs, which aims to achieve Water Framework Directive objectives. Some WWTPs can exceed their 'stretch' targets, provided that this is compensated by over-performance of other WWTPs to achieve the total catchment reduction.

This new permitting approach has required important investments by both Wessex Water and the Environment Agency to **establish initial P-discharge data, enable monitoring, define permit formulation and reporting obligations, and to modify IT systems** to enable and automate data reporting by the company and compliance assessment by the regulator. **Issues encountered with increased ferric dosing** to achieve lower discharge limits include foaming at some sites, increased sludge production and thinner sludge (more difficult to dewater), impacts on biofilters (ammonia emissions) and difficulties dosing ferric during low flow periods.

Rosemary Barker (photo) and **Emilie Cope, Severn Trent Water**, presented the challenges and questions of the decision approach for Total P permits on sites with permits between 0.5 and 1mg/l total P. Under the Water Framework Directive, Severn Trent Water are receiving a number of total phosphorus permits <1mg/l in AMP6, with more in AMP7. Four existing single oxidation sites and one oxibox site (with population equivalents p.e. <5000) with total P permits ranging from 0.5 to 0.7 mg/l have already been commissioned. On all these sites the approach has been taken to **phase the solution, with the iron coagulant chemical dosing into the ASP being installed first**. Performance was then monitored for 3 to 6 months, to ascertain whether tertiary solids removal (TSR) is required to ensure total P and iron compliance. After reviewing the data it has been agreed on all 5 sites that TSR is not required. The decision was very difficult on one site. It is critical that the site is operated optimally to meet the permits and that operators are upskilled. It has also been discovered that at these lower P levels the normal assumed ratios of ortho P to total P no longer apply, meaning **obtaining total P data is essential when making decisions**.

Chris Bullen, Siltbuster UK, summarised the advantages of assessing all inputs of phosphorus to catchments in order to **identify the most cost-effective possible reductions**, noting that source reductions can be the optimal solution. He noted that industrial phosphorus effluents are not taken into account in the pricing of discharge to WWTPs (Mogden formula uses COD and TSS) whereas abattoirs, dairy installations and food processers can have significant phosphorus discharges. He presented **successful case studies of phosphorus removal from discharges of small industries** in these sectors using iron coagulants and DAF (dissolved air flotation) and/or lamella clarifier for solids removal.

Phosphorus recycling

Dan Murray, Industrial Phycology, presented research into new biological processes for wastewater treatment, with the **objective of generating a useful product (algal biomass, which can be used for example as fish feed)** rather than a sludge. Existing algal systems either use ponds (large footprint, climate sensitive) or arrays of tubes or panels (costly investment and maintenance, climate and light dependent). The company's new pilot (75 m^3 capacity) under construction, with EU SME Instrument funding will use a mixed tank with high efficiency light: (LED generation of colours needed by algae for photosynthesis, columnated beam to enable penetration) and seperated hydraulics (maintain optimal levels of algae)). Initial trials with Wessex Water (1 m^3 capacity pilot) achieved 0.5 mgP/l or less with ~3 days residence time.

Patrick Melia, Kingston University UK, gave an overview of the **potential use of modified biochars as adsorbents for phosphorus removal from sewage**, with the objective of generating phosphorus-enriched biochar which could be used as a fertiliser. Available experimental data suggest that phosphorus uptake is primarily related to calcium and magnesium content, but also to specific surface area. Experiments show that biochars with added cations (Mg, Ca, Fe) can be effective in phosphorus removal from pure laboratory solutions, but there is not yet experience in real wastewater (with presence of competing ions and organics). Further work is underway to assess the kinetics of phosphorus removal and the effectiveness and practicalities of using these materials to remove phosphorus within a flow-through column.

Peter Balslev, Suez Water Denmark, presented the company's **Phosphogreen** struvite recovery process (see SCOPE Newsletter *n°121*) and experience from operation at Aarhus (84 000 p.e., biological phosphorus removal). The installation has **resolved major struvite deposit problems in sludge digesters and pumps, and reduced the phosphorus backflow in sludge dewatering liquor going to the works input from over 40% to 5%.** Struvite recovery in the digestate dewatering liquor can recover 20 – 35% of works inflow phosphorus as struvite. Installation of sidestream sludge hydrolysis upstream of digesters, and mixing pre- and post-dewatering sludge liquors to feed the struvite reactor can increase this to 40 – 45% phosphorus recovery. Struvite recovery is fully **compatible with future development of ANAMMOX** integrated biological N and P removal processes.

At Herning WWTP (150 000 p.e.), the **ROI (return on investment) of Phosphogreen struvite recovery is <7 years**, mainly due to over 100 000 €/year costs savings: reductions in consumption of ferric and polymers, increased biogas production, reduced electricity consumption (biological nitrogen removal), reduced sludge disposal costs and deposit avoidance.

Struvite sales at 350 €/tonne bring an annual revenue of nearly 50 000 €. The struvite is presently sold by the garden supplies company Kongerslev as PhosphorCare™ Luksus Havegodning ("luxury house garden fertiliser")

Nicolás Morales, Aqualia, presented full-scale experience recovering struvite at Guillarei WWTP (North West Spain, Consorcio de Augas do Louro water board). This 132 000 p.e. wwtp includes a full scale ANAMMOX based process, the **ELAN®** process, which treats the digestate liquor in a 115 m^3 sequencing batch reactor using granular biomass. The outer layers of the granule ensure partial nitritation while **ANAMMOX (Anaerobic Ammonium Oxidation)** takes place at the core of the granule. This lowers mainstream organics consumption (so increasing biogas production), reduces aeration requirements and reduces plant nitrogen discharges, and also reduces the alkali dosing necessary for struvite precipitation by removing ammonium and bicarbonate in the liquor. The **10 m^3/h struvite reactor, operating since 2015**, treats the full digestate stream after ELAN® treatment, and consists of a fluidised bed reactor and a decanter. Use of **magnesium oxide, a natural mined mineral** (**Magnesitas de Rubian Magal TC**) has been tested to reduce chemical costs for struvite production, but to be effective this powder product has to be previously converted in magnesium hydroxide because of its low water solubility by heating to 80°C and mixing for 4 hours.

Zoe Mathews and Philip Morgan, Power and Water, presented a possible nutrient recovery process for phosphate removal and recovery from municipal wastewater treatment plants using **magnesium alloy electrodes in an electrolysis reactor with ultrasound**. Trials are underway under the UKWIR Phosphorus working group employing iron electrodes. However, the use of magnesium alloy electrodes would offer the advantages of avoiding possible toxicity associated with iron discharges, maintaining alkaline pH conditions beneficial to biological processes, and precipitating phosphorus and ammonia as a struvite. A treatment validation stage using zeta potential is included in the process to ensure optimum treatment dose rate vs. nutrient loading. The reactor has been designed to work on gravity feed, electrodes are a simple slide-in replacement and the whole system is supplied with GSM for remote operation and control, making the process suitable for small-medium sized remote sites. Power consumption is typically 0.1 - 0.2 kWh/m3. The **Soneco®** reactor would be combined with final solids removal, for example using polymer flocculant and sand to achieve ballasted settling. Further development is under consideration to separate the precipitated struvite from the settled solids (organics, flocs, sand) for ballasted flocculation treatment.

Alex Veltmann, Waternet, presented struvite recovery at the Amsterdam West WWTP (1 million p.e., biological phosphorus removal), operating since 2013 (see SCOPE Newsletter *n°115*). The struvite reactor treats all of the digestate, upstream of dewatering, using airlift for CO_2 stripping (increasing pH to around 7.8 without alkali dosing) and magnesium chloride dosing. This has brought **important operating savings, estimated at 1.2 million € per year**, including avoidance of struvite deposit problems, improvement of sludge dewatering (from 21% to 23.5% dry solids) whilst decreasing polymer consumption (-20%) and enables the WWTP to achieve around 0.5 mgP/l discharge without chemical dosing.

Yariv Cohen, EasyMining (part of the RagnSells group, waste and resources management, Sweden, 2 700 staff), presented their **Ash2Phos** process for **recovery of phosphates and iron or aluminium salts from sewage sludge incineration ash** (see ESPP eNews *n°11*). The ash is dissolved in acid (without heat) then lime is added, enabling recovery of iron and aluminium as hydroxides which can be recycled as WWTP coagulants and of calcium phosphates, for processing to animal feed additives or to fertilisers. Heavy metals are extracted in a waste sludge for disposal. In pilot trials using fine fluidised bed sewage sludge incineration ash, 90% of phosphorus, 10-20% of iron and 60% of aluminium could be recovered. Waste acid (e.g. from incinerator gas scrubbers) could be used in the process. An industrial pilot is planned for end 2017. EasyMining is using COWI as an engineering partner.

Because of parallel sessions, it was not possible to attend all presentations. **Other presentations covered**: use of coal mine wastewater, which is rich in iron, to remove phosphorus, detailed presentations of testing of Mecana filter technology, of magnetite assisted settling (BioMag, Co-Mag) and of DynaSand® Ox (combined nitrification and P-removal), modelling and process control of enhanced biological phosphorus removal, granular sludge technology, phosphate detection sensing, engineered wetlands, asset optimisation, design lessons from CIP P-removal trials, and impact of enhanced phosphorus removal on sludge and biogas production.

Aqua Enviro BIG P Conference, 4th-5th July 2017, Manchester United Football Stadium (Old Trafford), England
www.aquaenviro.co.uk

SYMPHOS: Phosphorus industry and phosphorus use innovation

The 4th International Symposium on Innovation and Technology in the Phosphate Industry SYMPHOS was organized by OCP (www.ocpgroup.ma) at Mohammed VI Polytechnic University in Benguerir, Morocco. About 1000 international delegates attended the dense conference program and an exhibition showcasing the current solutions of major suppliers of the phosphate industry.

This summary of the workshops and parallel sessions, prepared by **Ludwig Hermann** is necessarily selective – only a selected number of workshops and sessions could be attended.

During the 3 days of this fourth edition of SYMPHOS, a large number of international suppliers and phosphate solution providers gave an overview of the state-of-the-art mining and processing technologies. **OCP** confirmed its leading role as a global phosphate industry with an increasing engagement in improving access to and use of fertilisers in African agriculture. Participants also enjoyed a thrilling gala dinner with an exuberant entertainment program of Moroccan and African musicians.

The program was organized in 7 plenary sessions, 4 workshops and 4-5 parallel sessions of 3-4 presentations. The workshops focused on 4 thematic fields, namely:

(1) "Industrial maintenance"
(2) "Sulfuric acid"
(3) "Cadmium"
(4) "Industrial management".

The thematic sessions dealt with "Slurry pipe", "Mining", "Agriculture", "P-sustainability", "Energy", "Biotechnology", "Phosphoric acid", "Beneficiation", "Valuable trace elements", "Material / corrosion", "Industrial maintenance", "Industrial technology", "New phosphated materials", "Fertilisers", "By-products", "Industrial technology", "Water" and "Soils management".

The conference started with **Seeram Ramakrishna (National University of Singapore)** with the very general presentation "Innovation for Sustainability" dealing with the nexus of innovation, sustainability and economic opportunities in manufacturing, energy, water, materials, transportation, mining, agriculture and food packaging sectors that many attendants perceived as "out of scope".

Fertiliser innovation

Presentations of the agriculture sessions focused on **access to fertilisers and their use efficiency in Africa** including the need for site-specific, individual formulation of primary, secondary and trace nutrients to cope with the widespread nutrient depletion and the subsequent low crop yields. However, a number of, partly industry (**OCP**) supported, organizations have been established to improve the situation in Africa. The beneficiation session was predominantly dealing with flotation and chemicals to improve selectivity. In the trace element session a number of scientists discussed different approaches to the **recovery of rare earth elements** (REE).

In Plenary 4, "Exploiting the potential role of fertilisers in increasing food production in developing countries", **Tekalign Mamo (Center for Soil and Fertilizer Research in Africa CESFRA, Mohammed VI Polytechnic University, Morocco)** discussed the still increasing level of food insecurity in Sub-Saharan Africa (SSA), taking into account climate change. In an effort to abate this problem, the CESFRA center that has prioritized to work in Africa to help farmers customize their fertilisers was launched at Mohammed VI Polytechnic University, aiming at reducing poverty in SSA and facilitate farmers' access to fertilisers.

In Plenary 2, **Bruce Rittmann (Arizona State University)** described in "Using biotechnology to make phosphate fertiliser more sustainable" two possible approaches based on microbial biotechnology (microalgae and nitrifying bacteria) aimed at preventing the precipitation of phosphate into mineral forms that are poorly available to plants. The first takes advantage of the ability of microalgae to rapidly adsorb large amounts of phosphate, which is then readily available for plant use. The second involves fortifying the fertiliser with nitrifying bacteria, whose metabolism naturally produces acids that lower pH and minimize transformation in soil of fertiliser phosphorus into mineral forms. The author claims that making the P more available would lower the application rate and so the risk of P loss to run-off.

In Plenary 6 "REACH legislation and how it affects fertiliser products innovation" France based researchers **Juan Gonzalez-Leon (Centre de Recherche Rhône-Alpes ARKEMA CRRA), F. Chittaro and Nadège Guerault (CECA, La Garenne-Colombes)** discussed the EU REACH legislation and its impacts on fertiliser products innovation.

Debisi Araba (International Center for Tropical Agriculture (CIAT) – Regional office for Africa, Nairobi) discussed in Plenary 7, "Leveraging the combined powers of science and entrepreneurship in African agricultural transformation" the potential for enhancing and sustaining the productivity of specific farming systems through more efficient use of inputs and natural resources, helping to identify improved management practices for specific conditions, with the aim of curbing soil degradation. Renewed cooperation between research institutions and private entrepreneurs, at all levels and from boardrooms and laboratories, to the agro-dealers and farms, focusing at 4 areas is proposed: (i) profiling soil fertility, (ii) digital soil mapping in key countries, (iii) fertiliser recommendations and on-farm field trials, and (iv) capacity building.

Sustainability

The P-sustainability session was also scheduled for the first afternoon and equally well attended. **Christian Kabbe (Berlin Centre of Competence for Water)** presented the current state of P-recovery activities in "Circular Economy – Challenges and Opportunities for Phosphorus Recovery & Recycling from Wastes in Europe", **Tom Bruulsema (IPNI, Canada)** presented "Industry Initiatives Enhancing Phosphorus Sustainability" and **Ludwig Hermann (Outotec and ESPP)** presented "Mining, Processing and Using Phosphates in a Circular Economy" focusing on the framework provided by the 17 Sustainable Development Goals, the Paris Agreement (COP21) and the Circular Economy Package of the European Commission and the opportunities for improving the sustainability of phosphate mining and processing by partly proven, partly novel technology approaches.

Three different approaches for decadmiation were presented in the Cadmium Workshop, from cadmium precipitation with an organic additive (**Solvay**'s ACCOPHOS®) through thermal decadmiation (**Outotec**) to solubilizing phosphates with silicates and thus stabilizing cadmium while making the trace nutrient zinc plant available (Russian Academy of Science, Institute of Basic Biological Problems). Both workshops attracted a large number of attendants.

Energy applications of phosphorus chemistry

The energy session was partly dealing with phosphate use in batteries. It also included one very interesting presentation by **Lars Amsbeck (DLR Institute of Solar Research, Germany)** about solar sludge drying and thermal beneficiation by using concentrated solar power (CSP), a combination of heliostats and a receiver to produce and store processing heat (up to 1000°C) through selected solid heat carriers. This approach, allegedly already competitive with liquid fossil fuels, could have a high CO2 saving potential in countries with high solar radiation intensity like Morocco.

In Plenary 3, "High energy and high power electrodes for automotive battery applications" **Khalil Amine (Argonne National Laboratory, Lemont, USA, and Mohammed VI Polytechnic University, Morocco)** discussed strategies to increase the energy density of LiFePO4 and LiMn1-xFexPO4 cathodes without compromising their power capabilities.

Phosphate industry innovations

Industrial maintenance was the most popular thematic field with one workshop and numerous presentations covering operations and maintenance of phosphate mining and processing. It included case studies of simulation based engineering (**Andritz**), case studies of incidents, lean production processes (**OCP**) and spare parts management (**Thyssenkrupp Industrial Solutions**). With regard to materials handling and processing, bulk handling systems as well as screening, grinding, pumping, dewatering and prilling solutions were presented alongside with simulation and digitalization options.

The Sulfuric Acid Workshop dealt with debottlenecking (**Outotec**), in-situ differential scanning calorimetry (**DSC**) for sulfuric acid catalyst development (**MECS Europe/Africa**), energy efficiency improvements by making Clean Water (**Jacobs Engineering, USA**) and full energy recovery by converting heat from sulfur combustion to high and low pressure steam (**HEROS™ by Outotec**) as well as emission abatement (**Outotec**).

Pascal du Bois d'Enghien and Youssef Riahi (MECS Europe/Africa) presented in Plenary 5, "Replacement and maintenance strategy", corrosion resistant stainless steel alloys for sulfuric acid plants.

The slurry pipe session Monday afternoon dealt, among others, with the adoption of the eight 500 tpd P2O5 **phosphoric acid plants in Jorf Lasfar** to feeding wet phosphate slurry by the new pipeline (capacity 38 Mt/year) connecting the **Kouribga mine** to Jorf Lasfar. At the same time, the phosphoric acid production is concentrated in 4 new plants, each with a capacity of 1350 tpd P2O5, increasing the total daily capacity from 4000 to 5400 tons. This project allows reaching an increased availability and other improvements such as the reduction of fluorine emissions with a rate of less than 5 mg/Nm3 and improving the chemical efficiency to around 95%. Digitalization and automation was in the focus of presentations in the mining session.

During the phosphoric acid session presenters discussed process options, in particular hemi- vs. dehydrate for increasing the plant capacity during a revamp of phosphoric acid plant (**John Wing, Phosacid**). Hannu **Laitala (Outotec)** described the company's acid purification approach based on solvent extraction. In addition plant design and digitalization was on the agenda of different sessions as well as fluorine recovery and use, among others by **Hadrien**

Leruth (Prayon). SNC-Lavalin and Prayon also presented "A Phosphoric Acid Process Simulator for Knowledge Transfer".

US Phosphorus RCN

The US P-RCN (2013-2017, Phosphorus Sustainability Research Coordination Network, funded by US National Science Foundation, see SCOPE Newsletter *100* and *114*) held its final meeting in Washington DC, 16-18 May 2017. P-RCN facilitated networking between scientists interested in phosphorus (P) sustainability by bringing together around 40 scientists from the US and the rest of the world for five working meetings.

This has enabled these scientists to jointly publish a number of **review/analysis papers** in scientific journals (list below). A number of key issues for phosphorus sustainability have been addressed by the P-RCN group (below) and some **important outstanding questions were identified and discussed at this last meeting**. The P-RCN scientists will use the remaining months of the project to finalise a number of papers underway (see in list below) and to propose approaches to these outstanding questions.

The institutes who have participated in P-RCN for all or part of the five years are the following US universities Arizona State University (lead), Arkansas, Heidelberg, Marquette, Minnesota, South Florida, Stevens Institute of Technology, Toledo, Washington State; non-US universities: Bangor Wales, Belfast QUB UK, Cape Coast Ghana, CEH UK, Tohoku Japan, Osaka Japan, Lancaster UK, Laval QC Canada, University of Technology Sydney Australia, China Agricultural University, Chinese Academy of Sciences; other organisations: IPNI (International Plant Nutrition Institute), ESPP (European Sustainable Phosphorus Platform), Agri Food & BioSciences Institute UK, AAFC (Agriculture & Agri-Food Canada), USDA-ARS (U.S. Department of Agriculture – Agricultural Research Service).

Key issues addressed by P-RCN

Through five years of collaboration between the more than 20 institutes in P-RCN, the following issues have been identified as important to the phosphorus sustainability challenge:

- **Legacy phosphorus**: fertiliser application since the second half of the twentieth century led to a considerable current accumulation of so-called "legacy" phosphorus in soils and in water system sediments. This has environmental, agronomic and resource consumption implications. A key paper from P-RCN collaboration documents this phenomenon for three river basins: Thames UK, Yangtze China, and Maumee USA (**Powers et al. 2016**). The implications of "legacy phosphorus" are discussed below.

- **Phosphorus removal and recycling technologies**: a wide range of different approaches and technologies for phosphorus recycling are today available. No one solution fits all requirements or contexts. A challenge is to provide up-to-date information to potential users and investors (see SPA Forum – Newtrient technology catalogue – in this SCOPE Newsletter). Note that this P-RCN question led to the **development of the WETSUS-ESPP inventory and summary of technology assessments of phosphorus recycling technologies, updated on the ESPP website** *www.phosphorusplatform.eu/p-recovery-technology-inventory*

- **Metrics**: on the one hand, there is a problematic lack of accurate, coherent and up-to-date data concerning phosphorus flows. This is widely noted (see e.g. **ESPP DONUTSS meeting 2016** *www.phosphorusplatform.eu/donutss*). The most recent phosphorus flow data for the USA date from 2007 (**Suh et al. 2011** *http://dx.doi.org/10.1016/j.chemosphere.2011.01.051*). On the other hand, there is a need for regulators and industry to have reliable phosphorus flow and impact data, to support decision making. The P-RCN group is developing the outline for a "phosphorus footprint" outline methodology.

- **Nutrient – water – energy nexus**: the P-RCN group note that phosphorus sustainability is inter-dependent with management of water resources, energy, other nutrients, and the complete food system. This led to the concept of **"total value" of phosphorus recycling,** where economic viability can result from integration of phosphorus recovery with management of nitrogen, water and energy.

- **Transition Management Pathways**: action on phosphorus is needed to address food security, resource dependency and environmental impacts. But phosphorus management is complex, locally specific and involves a wide range of stakeholders. Collaborative governance methods are needed to facilitate implementation of innovation in conservative industries such as water treatment and agriculture. In particular, a **mapping exercise of transition pathways to sustainable phosphorus management in society was carried out for North America**, based on consultation of the participants at the 2015 NAPPS Forum (NAPPS was the previous name of the Sustainable Phosphorus Alliance).

Outstanding question: Where is the "legacy phosphorus" and does it matter?

Powers et al. 2016 shows in three different rivers worldwide that **a significant part of fertiliser applied over recent decades seems not to leave the basin within the time frame considered** (comparison of basin P inputs to outflows in river total phosphorus) but does not show what part of the phosphorus is accumulating, over this time scale, in agricultural soils and what part in river bed sediments or sediments behind dams. Time scale is essential as phosphorus moves more slowly through soil-river systems than is often considered. Further key questions are what P sources contribute more and how to mitigate these?

However, **it is widely considered that some of Europe's and North America's farm soils (both arable and pasture) accumulated soil phosphorus over past decades** (e.g. estimate of 550 kg P/ha average worldwide over the period 1965-2007, **Nesme and Pellerin, COMIFER 11th April 2017 Paris**, in this SCOPE Newsletter). This is logical, as in the past phosphorus was widely applied to soil up to the critical "breakpoint" above which crop response to phosphorus diminishes (see **Johnny Johnston** in SCOPE Newsletter *98*). This often results in a **soil build-up of phosphorus, by filling up part of the soil's buffering capacity with phosphorus, so that the soil can supply adequate phosphorus to the plant**. Subsequent applications of P are made primarily to maintain soil available P by replenishing crop removal. However, in some farms continued applications of phosphorus led to soil available P levels approaching a second critical breakpoint, beyond which the concentration of P in runoff water increases dramatically. This is particularly the case in regions with manure production, where manure application was often based on nitrogen not phosphorus crop needs, resulting in excess phosphorus application. In many jurisdictions, nutrient management regulations now limit such surplus applications of P to soils. Chinese farmlands also show a resulting accumulation of P due to overuse of chemical P fertilisers in past decades, leading to soil available P as Olsen-P increasing from 7.4 mg kg^{-1} in 1980 to 21 mg kg^{-1} in 2006 (**Li et al., 2011, Plant and Soil; Li et al., 2015, AMBIO**), but this situation is being overcome and total P fertiliser consumption in China starts to level off due to better root-zone nutrient management and **"Zero increase" fertilisation policy**. This plans an annual increase in fertiliser use of <1% 2015-2019 and no further increase after 2020 without yield loss (**Jiao et al., 2016, Journal of Experimental Botany**).

An important point is that it takes a number of years of order of magnitude longer for crops to draw down soil phosphorus accumulation than it takes to build it up.

Questions today are:

- **To what extent does this increased soil P content result in significantly increased phosphorus losses to surface water** (and eutrophication risk), if "legacy P" levels are not higher than the critical breakpoints above and if actions are taken to limit soil erosion (these actions are necessary anyway, independently of phosphorus)?
- **Is soil "legacy phosphorus" today still an issue** in regions (e.g. much of Europe) where farmers significantly reduced P fertiliser application after the 2008 price peak?
- **What about regions such as Africa, Brazil or Australia?** Here soils are phosphorus-poor and/or have high phosphorus buffering capacities: should phosphorus continue to be applied above crop needs to improve soil fertility in these regions and how to combine this with concerns about waste, resources, energy and the environment?

Depending on the answers to the above questions, legacy soil phosphorus might be considered a positive in some situations (enabling a stock of phosphorus for farmers in case of supply disruption or price peaks, and enabling balanced fertiliser application, to fertilise the crop and not the soil) or negative in others (increased losses to surface waters, energy and resource consumption, without significant increase in crop productivity).

Outstanding question: how to measure soil phosphorus

For various reasons, **current soil phosphorus measurement methods** (such as Olsen P which is widely used in Europe) are considered by some to be inadequate or inappropriate:

- Maybe not a good indicator of **plant available phosphorus**. Olsen P measures readily soluble phosphorus (P), whereas plants can access P which is bound to minerals or in organic form, for example by modifying rhizosphere chemical and biological processes through carboxylate exudation, proton release, and acid phosphatase secretion (Shen et al., 2013, Journal of Experimental Botany; Jiao et al., 2016, Journal of Experimental Botany), although this will depend on the crop, the climate, the soil conditions.
- Olsen P may **underestimate risk of runoff or phosphorus losses to surface or ground water**. On the other hand, methods often used in the USA such as Mehlich-3 and Bray-1 can overestimate the risk of P runoff, as the acid extractant solubilizes some Fe and Ca-P compounds built up in soil following long-term by-product applications.
- May not be a good **indicator for phosphorus present in organic forms in the soil**, in particular phosphorus provided by organic fertilisers (composts, digestates, manures, sewage biosolids …)
- May not properly **mimic plant root absorption** and cannot represent the soil available P at a relatively broad gradient of soil P fertility.

Thus, new approaches are needed to accurately evaluate the P availability in soil because only the soil P taken up by plant can be regarded as bioavailability (**Shen et al., 2011, Plant Physiology**).

A number of **innovative, new soil phosphorus test methods** are today available, such as

- **DGT (Diffusive Gradients in Thin films)** technique, which mimics the physico-chemical uptake of P by plant root (see **Six et al, in SCOPE Newsletter** *112*)
- **Resin extraction** method as root simulator
- **Soil incubation tests** (see **COMIFER 11th April 2017 Paris**, in this SCOPE Newsletter)
- **P-PAE (Plant Available Elements**, extraction with calcium chloride), P_{AL}(ammonium lactate extraction) or P_W (water extraction), see "Phosphorus Use Efficiency of Bio-Based Fertilizers: Bioavailability and Fractionation", **Vaneeckhaute et al., Pedosphere 2016** *http://dx.doi.org/10.1016/S1002-0160(15)60045-5*

On the other hand, both regulators and the agricultural community are unwilling to change, because a large bank of past soil and agronomy (e.g. crop response) data is available for existing test methods, and results of new methods will not be comparable, so that **farmers and farm advisors will not be able to interpret them**, without costly and time consuming field soil-crop response trials (a wide range of trials using the new tests on different regional soils, P status, … would be needed to try to approximately calibrate results with existing test data).

Also, an issue with the current testing methods, and possibly even more so with the methods described above, is the **time and cost necessary to carry out the test**. Unlike nitrogen, where N application can be adjusted real-time by the tractor using leaf colour of the growing crop, instant and real-time P analysis is not available. This limits to what extent farmers can realistically adjust P application to different parts of the field and to seasonal conditions (real crop needs).

Outstanding question: What is meant by "phosphorus efficiency"

It is often stated that phosphorus use is very inefficient. For example: "<20% of P mined for fertiliser reaches the food products consumed" (**Jarvie et al., P-RCN, 2017**, taken from **Neset & Cordell 2012**). More specifically, **Van Dijk**'s study of EU phosphorus flows (see SCOPE Newsletter *117*) indicates that "**In crop production: 70% was taken up by crops**".

However, Van Dijk's data are from 2005, when Europe was still applying high levels of phosphorus fertiliser (before the 2008 price peak) and was probably accumulating "legacy P" in agricultural soils. Eurostat *data* suggest that the average "gross balance" of phosphorus on European agricultural land has halved since 2005, with a total gross balance of around 350 000 tonnes P/year for Europe in 2013 (most recent data).

It thus seems clear that **a better assessment of where phosphorus losses are really occurring is necessary**, with up to date figures, for different world regions, in order to identify where actions to reduce losses can be effective.

Other outstanding questions:

- **Ecosystem services and costs**. The P-RCN group noted that is a glaring absence and insufficiency of economic data concerning the benefits of improving phosphorus management. The only estimate of job creation possibilities from phosphorus management and recycling is ESPP's informal document from 2013 which suggests that phosphorus stewardship could generate 66 000 jobs in Europe (not taking into account jobs "saved" in farming), link *www.phosphorusplatform.eu/images/ESPP_jobs_and_employment_outline_29-5-13.pdf* The only estimate of the costs of ecosystem damages resulting from eutrophication is 1.5 – 3.8 billion US$/year for the USA (**Dodds et al. 2009** see SCOPE Newsletter *72*).
- **Catchment modelling**. Despite considerable efforts worldwide, catchment models for the prediction of phosphorus losses suffer from high uncertainties: it is complex and difficult predicting phosphorus losses at the catchment and basin scale. In all cases, considerable local adaptation to account for local context and farming practices is necessary. This is partly because a large proportion of phosphorus losses often come from 'particularities' such as storm flows, localised soil erosion, specific problems with animal or manure management or small areas with high losses.
- **Long term field trials**. Phosphorus in soil and phosphorus crop productivity need to be considered over long time periods (ten years or more), to take into account soil P accumulation and changes in phosphorus forms in soil. Long term field trials are thus essential, and this message should continue to be emphasised to R&D funding bodies.
- **Agricultural 'BEMP' (Best Environmental Management Practice) fact sheets**. Such tools exist, to inform farmers and agricultural advisors to reduce nutrient losses, produced by a number of organisations (SERA17, EU COST, Baltic, Canada …) but would strongly benefit from updates to take into account new knowledge concerning, e.g. long-term performance of buffer strips or impacts on phosphorus run-off of "no till". Optimisation could be achieved by bringing together the different sets of fact sheets existing worldwide to produce updated sets for each region. This project discussed in 2015 has not progressed (see SCOPE Newsletter *115*).

Selected P-RCN joint publications

Through the P-RCN activities, the participants have published a number of **joint papers addressing general questions of phosphorus sustainability**, listed below. The P-RCN participants have published during the project's duration a larger number of papers which benefited from input and enrichment from the P-RCN collaboration process.

P-RCN publications

Doody D, Withers P, Dils R, Prioritizing waterbodies to balance agricultural production and environmental outcomes, Environ. Sci. Technol. 2014, 48(14), 7697-7699
http://dx.doi.org/10.1021/es5024509

Doody D, Withers P, Dils R, McDowell R, Smith V, McElarney Y, Dunbar M and Daly D, 2016 Optimising land use for the delivery of catchment ecosystem services Frontiers in Ecology and the Environment 14(6) 325–332 http://dx.doi.org/10.1002/fee.1296

Haygarth P, Jarvie H, Powers S, Sharpley A, Elser J, Shen J, Peterson H, Chan N, Howden N, Burt T, Worrall F, Zhan F, Liu X, Sustainable phosphorus management and the need for a long-term perspective: The legacy hypothesis, Environ. Sci. Technol., 2014, 48 (15), pp 8417–8424 http://dx.doi.org/10.1021/es502852s

Jarvie H, Johnson L, Sharpley A, Smith D, Baker D, Bruulsema T, Confesor R, Increased Soluble Phosphorus Loads to Lake Erie: Unintended Consequences of Conservation Practices? Journal of Environmental Quality, 12, 2017 http://dx.doi.org/10.2134/jeq2016.07.0248

Mayer B, Baker L, Boyer T, Drechsel P, Gifford M, Hanjra M, Parameswaran P, Stoltzfus J, Westerhoff P, Rittmann B, 2016. Total value of phosphorus recovery. Environ. Sci. Technol. 50, 6606-6620, http://doi.org/10.1021/acs.est.6b01239

MacDonald G, Jarvie H, Withers P, Doody D, Keeler B, Haygarth P, Johnson L, McDowell R, Miyittah M, Powers S, Sharpley A, Shen J, Smith D, Weintraub M, Zhang T, 2016. Guiding phosphorus stewardship for multiple ecosystem services. Ecosystem Health and Sustainability 2(12):e01251. http://doi.org/10.1002/ehs2.1251

McDowell R, Dils R, Collins A, Flahive K, Sharpley A, 2016, A review of the policies and implementation of practices to decrease water quality impairment by phosphorus in New Zealand, the UK, and the US. Nutrient Cycling in Agroecosystems 104:289-305 http://dx.doi.org/10.1007/s10705-015-9727-0

Powers S., Bruulsema T, Burt T, Chan N, Elser J, Haygarth P, Howden N, Jarvie H, Lu Y, Peterson H, Sharpley A, Shen J, Worrall F, Zhang F, Long-term accumulation and transport of anthropogenic phosphorus in three river basins. 2016. Nature Geoscience 9: 353¬356. http://doi.org/10.1038/ngeo2693

Rowe H, Withers P, Baas P, Chan N, Doody D, Holiman J, … Weintraub M, 2016, Integrating legacy soil phosphorus into sustainable nutrient management strategies for future food, bioenergy and water security. Nutrient Cycling in Agroecosystems, 104(3), 393–412. http://doi.org/10.1007/s10705-015-9726-1

Sharpley A, Jarvie H, Kleinman P, Flaten D, 2016. Reframing phosphorus stewardship for resilience in food-energy-water security. Innovations at the Food-Energy-Water Nexus White Papers. National Science Foundation, Washington, DC. 4 pages. https://www.agronomy.org/files/science-policy/white-papers/2.pdf

Sharpley A, Kleinman P, Jarvie H, Flaten D, 2016, Distant views and local realities: The Limits of global assessments to restore the fragmented phosphorus cycle. Agric. Environ. Lett. 1:160024. http://doi.org/10.2134/ael2016.07.0024

Withers P, Elser J, Hilton, Ohtake H, Schipper W, van Dijk K, Greening the global phosphorus cycle: How green chemistry can help achieve planetary P sustainability, Green Chemistry, 2015, http://dx.doi.org/10.1039/C4GC02445A

North America Phosphorus Forum

Nearly one hundred researchers, administrations and companies from the USA and Canada met in Washington DC, May 19th 2017, at the second stakeholder meeting of the Sustainable Phosphorus Alliance. The first meeting took place in 2015 (NAPPS, see SCOPE Newsletter *100*). The meeting discussed the conclusions of the NSF P-RCN (National Science Foundation Phosphorus Research Coordination Network, see this Newsletter) and the Newtrient US dairy's innovative industry initiative on manure phosphorus management technologies.

The Forum was the launch point for the North America sustainable phosphorus action platform, which has now finalised its structure and mode of action under the name "**Sustainable Phosphorus Alliance**" *https://phosphorusalliance.org* after several years establishment phase under the name NAPPS. The Alliance today already has as members: OCP, FEECO International, NACWA, Ostara, Renewable Nutrients, WE&RF, Consultants Allied, Brookside, The Sustainability Consortium, with others underway.

The Alliance's near future activities will include a **working group on phosphorus recycling from sewage biosolids and manures**, and a webinar on **nutrient emissions trading** (watch at *www.youtube.com/watch?v=NFci0_HIDDY&feature=youtu.be*).

Jim Elser, Sustainable Phosphorus Alliance, opened the meeting, underlining the **complexity of the phosphorus sustainability challenge**, because different groups and different regions have differing objectives. In North America, the need to act on phosphorus management is clear, with a strong driver being ongoing issues with algal blooms in lakes and rivers, impacting recreation value and even in some cases water supply. At the same time, livestock producers face pressure from residents and environmental groups, including tort cases for nutrient pollution and legal cases proposing to classify manure as a "hazardous waste".

However, we should also remember the positive news which doesn't make the headlines: **phosphate fertiliser is key to feeding the planet**. Improved phosphorus management can create new business opportunities and jobs in recycling and innovative techniques, and is essential to the economic sustainability of farming.

Steve Rowe, Newtrient *www.newtrient.com*, emphasised the opportunities offered by nutrient recycling calling participants to "see the spaces in the forest, not the trees" (the obstacles). Newtrient (see article in this SCOPE) is a new type of innovation company, with environmental, economic and social objectives, with an underlying goal to restore society's confidence in farmers. Its objectives are to **reduce the dairy industry's environmental footprint whilst also making this economic, in order to produce both food and clean water**.

Newtrient aims to **make money from manure through innovative valorisation approaches**. Farmers should have three products: milk, meat and manure. The fertiliser industry can find opportunities for new markets with local recycled fertiliser products based on manures.

To take this forward, Newtrient has developed an **online 'catalogue' of manure treatment suppliers and technologies** (see article in this SCOPE), including identifying solutions which Newtrient's experts consider to have potential and working with suppliers to incubate and develop promising technologies.

However, he notes that agriculture is a "price taker", with the **retail and food industries setting the price and generally not paying for environmental quality**. Innovative approaches are needed to make environmental quality economically viable for farmers.

One promising approach is an **environmental services or emissions reduction marketplace**. This could work if established at a wide scale, and if a recognised system is established for validating and certifying farmers' emissions reductions. Farmers can today often reduce nutrient emissions at significantly lower cost than making further reductions to point sources which are already regulated (increasing cost of removing the next kg of phosphorus). Development of credit certification criteria and a trading clearing house system are underway with the States of Vermont and Wisconsin.

Michael Weintraub, Toledo University, USA, presented the work of the P-RCN ecosystem services group, looking at phosphate use and losses to the environment. A key message is that **phosphorus losses are in many cases not directly connected to inputs to agricultural systems**. Large river basin examples in different parts of the world show that phosphate fertiliser use has been reduced over recent decades, but basin outflows in river water have not fallen.

This disconnect between farm phosphate inputs and surface water levels results from a range of factors, including accumulation in the twentieth century of **"legacy" phosphorus stocks** in both agricultural soils and in aquatic sediments, high losses during storm events or preferential pathways (such as cracks in soil which allow direct runoff to water bodies).

Over application of fertiliser in China has resulted in considerable increases in soil available phosphorus: from 7.4 to 21 mg-Olsen-P/kg soil from 1980 to 2006. On the other hand, recent studies in North China have shown that no application of phosphorus for two years did not reduce crop yield for intensive maize production, suggesting a role of soil accumulated P in sustaining maize grain production (Jianbo Shen, China Agricultural University, unpublished data).

Brooke Mayer, Marquette University, USA, summarised the P-RCN phosphorus removal and recycling group conclusions. P-RCN concludes that **phosphorus recycling technologies are today available, but that they are not implemented because of economics or absence of policy drivers.** The recovered phosphate product in many cases does not today cover the cost of recycling. Note: a similar conclusion was reached at the P-REX/ESPP/EU Commission workshop, Berlin, 2015, see SCOPE Newsletter *111*.

However, the economics can change if phosphorus recovery is part of a **"total value" proposal**, for example in synergy with recovery of energy, nitrogen and other materials, or because of other 'services' delivered, for example improving waste water treatment performance (often the case for struvite recovery in sewage works). Other 'services' such as Sustainable Development Goals (food system security, equity, water quality) are today however not monetarised.

P-RCN underlines that solutions need to be adapted to specific local situations. It is **necessary to identify where are significant phosphorus flows potentially available for recovery in different regions and industries** and in what form is the phosphorus (concentrated or dilute, organic or inorganic, soluble or particulate) because this will define opportunities, appropriate intervention points and technologies, and costs for improving water quality or for nutrient recycling.

Economic viability may come from some kind of **pollution credit system**. For example, **Boise city, Idaho**, is building phosphorus removal system on an agricultural drain, because this is more economic than removing phosphorus to tighter discharge limits at the municipal waste water treatment plant. The drain treatment will be a near 20 ha system with sedimentation basin, constructed wetlands, aluminium chemical dosing and settling ponds. The US EPA permitting *information* specifies that the municipal sewage works discharge consent will be 0.25-0.35 mgP/l monthly average, with an obligation to achieve 0.07 mgP/l in the receiving stream. The drain treatment system will be obliged to remove 1.5x the phosphorus load resulting from the sewage works discharge being higher than 70 µgP/l and has a design capability to remove 28 tonnes of P per year. The total phosphorus removed from the watershed will thus be higher than by requiring the tighter limit (0.07 mgP/l) at the municipal sewage works.

Heidi Peterson, Minnesota Department of Agriculture, USA, presented P-RCN's work on the transition process towards sustainable phosphorus management. She noted that since the mid-1970's, Minnesota's agricultural niche innovation and political actors have aligned, resulting in a transition toward more efficient phosphorus use. In the 1990's, phosphorus input in mineral fertilisers was approximately equivalent to crop phosphorus offtake (efficiency near 100%; however, lower where manure phosphorus was additionally applied). Over the last decade, since the phosphorus price peak, **efficiency has exceeded 100%, or in other words, farmers are "mining" legacy soil phosphorus.** At this same time, advancements have been made in crop genetics and harvesting efficiency. To further improve crop phosphorus efficiency, work is needed to enhance precision agriculture technology so that real-time soil phosphorus tests (see above) for detail-scaled field zones could inform fertiliser application.

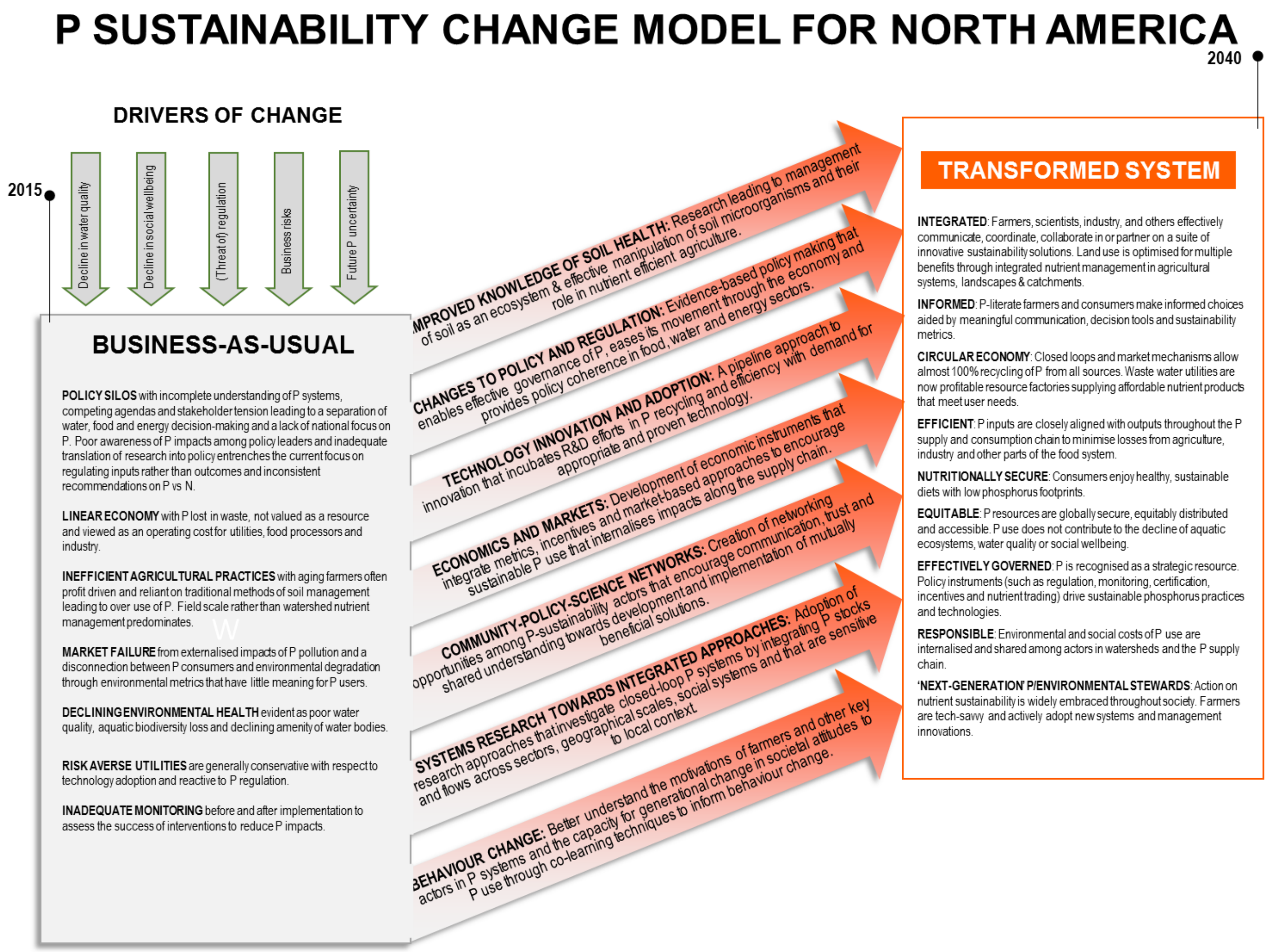
P-RCN noted that the transition to **more sustainable phosphorus management will necessitate innovation, but also collaboration and integration to ensure uptake**.

Dana Cordell, University of Technology Sydney, presented a **phosphorus sustainability change model for North America**, resulting from the discussions and input from stakeholders at the first North America Sustainable Phosphorus Alliance (NAPPS) Forum 2015.

This model identifies key aspects of a **desirable future phosphorus management**, drivers which might push to move towards this ideal, and transition pathways / actions which might enable the necessary changes. There is general agreement that technological and social innovation is necessary for sustainable phosphorus management, and this model aims to facilitate uptake of innovation by synthesis and legitimisation across a wide range of stakeholders. **Key aspects of a sustainable phosphorus future for North America, as proposed by the 2015 Forum participants, include collaboration across industry**

sectors and different stakeholder sectors, a circular economy for nutrients, nutrient policy governance and shared responsibility for societal costs. Public water and waste utilities and farmers are conservative, so important drivers for change will be fear of regulation and supply insecurity.

Possible **proposed pathways** to change include: regulation, innovation, bio-economy, removing regulatory barriers, information about the time-lag between phosphate use and environmental impacts, facilitating capital investment and demand for healthy food and diet. The model developed is presented in the figure. It aims to provide a high-level blueprint for change and a discussion basis for engaging stakeholders. The proposed objective of near 100% phosphorus recycling by 2040 may not be realistic, given trade-offs with other impacts and costs, but provides a basis for scenario proposal.



Chris Thornton, European Sustainable Phosphorus Platform (ESPP), summarised developments driving phosphorus sustainability in Europe (see slides at *www.phosphorusplatform.eu/links-and-resources/presentations*), from the 'command and control' Urban Waste Water Treatment and Nitrates Directives of 1991, through the quality objectives Water Framework Directive of 2000, to **today's emphasis on the nutrient circular economy to reduce dependency on phosphorus imports and create jobs**, economic opportunities and net income for farmers.

Mike Schmid, Renewable Nutrients, presented the company's process to treat manure and recover calcium phosphate (**Quick Wash**®, see SCOPE Newsletter *119*). He noted that with triple super phosphate currently selling at US$300/tonne (1500 $/tonne of phosphorus) the economic value of phosphate recycling is not with the product but can be with other benefits.

Joseph Ziobro, US EPA, presented the Agency's 2016 **manure Nutrient Recycling** *Challenge*. This received 75 entries, of which 34 were selected for phase II "incubation" (see SCOPE Newsletter *121*). The 34 innovator teams have been developing technology designs in Phase II based on their selected prototypes. In some cases, innovators have already built technologies and are partnering to build and test their technologies on commercial livestock operations. He also noted that phosphorus recycling is not economic alone, but can be so if combined with energy recovery. Subsidies are needed to support adopters of novel technologies, in order to alleviate innovation risks and costs. At the same time, dialogue is needed between US States concerning manure spreading limits with the aim of achieving federal water quality objectives.

Kraig Westerbeek, Smithfield Foods, the world's biggest pig producer, explained that the company has ambitious environmental objectives, including reducing greenhouse emissions by 25% by 2025. The use of phytate and improved feed programmes and diets has enabled a **nearly 50% reduction in phosphorus input per pig since the 1990's**. Smithfield notes that manure treatments (such as lagoons or anaerobic digestion) concentrate the phosphorus. Farmers have already paid for this phosphorus once, so it would be positive to recycle it to animal feed or to other value uses, subject to food safety. Smithfield's retail and food customers are demanding sustainability: how to sell nutrient recycling as added-value in this market?

Participants noted that new approaches to fertilisation are necessary. Phosphorus is over-applied in the Chesapeake Bay catchment because farmers want to add organic matter and sulphur to soil. Nearly 4 million US$ funding is available in the catchment to develop treatments of pig, horse and chicken manures.

Participants also noted that a US Senate Bill is *under discussion* to offer a 30% **tax credit for nutrient recovery** (Agriculture Environmental Stewardship Act S. 988).

Tom Bruulsema, IPNI (International Plant Nutrition Institute) presented the **"4Rs" approach**: fertilisation with the right fertiliser (accessible to the

plant as needed), at the right rate (according to crop needs), at the right time (when the plant needs it), at the right place (where the plant can access it). Farm trials have shown that productivity is maintained, soil health is ensured, nutrient use efficiency is improved and nutrient losses to the environment are reduced. Overall in North America, since 2010, soils with elevated phosphorus levels are becoming less widespread and **today soil phosphorus levels are often such that phosphorus needs to be applied to replace crop uptake**, or even restored to improve productivity.

Karl Wyant, Helena Chemical Company (agricultural advisory), underlined that farmers' concern is not sustainability, per se, but savings on **input cost per hectare** and application efficiencies. On-tractor monitoring of crop offtake, seeding control, satellite information and real-time data analysis, combined with soil phosphorus tests in several field zones can enable variable application of different fertilisers (N, P) according to crop needs in different parts of the field. This can save farmers money by optimising fertiliser use, and brings environmental benefits as a by-product. **The forms in which fertilisers are delivered must be flexible and adapted to farmers' equipment and habits** in different regions: solids, liquids, different chemicals, organic and mineral. He notes that distributors and farmers are already widely using recycled nutrient materials such as composts and manures. Manures pose specific issues which are an obstacle to use: variable nutrient content (not compatible with precision farming), possible bacterial contamination and salinity.

Galen Mooso, JR Simplot, noted that the company is both a phosphate mineral producer (with two phosphate mines in the USA, <2% of world production) and a large user (in particular for potatoes, which have high P needs). He also emphasises the **importance of precision agriculture**, with GPS on-tractor controlled variable fertiliser application, combining different N, P, K fertilisers on the tractor according to varying crop needs across the field. A key is therefore soil phosphorus tests to understand variability of phosphorus in soils at the within-field level.

Chris Peot, DC Water, underlined the **importance of sewage biosolids valorisation for water treatment sustainability**. DC Water operates the world's biggest tertiary (P-removal) sewage plant at Blue Plains, serving over 2 million population). Iron salts are used to achieve a discharge limit of 0.1 mgP/l. Anaerobic digesters convert half of the biosolids carbon to renewable energy, and the other half is recycled to farmland. The US produces a total of over 9 million tonnes/year (dry matter) sewage biosolids, containing 1-6% P (350 000 tonnes/year of phosphorus). Half of this is currently landfilled, so not recycling the phosphorus.

In the DC area, sewage biosolids are mostly positively welcomed. They are branded as "**DC Bloom**" and recognised to improve drought resistance by restoring soil carbon, and as an economic alternative to mineral fertilisers. However, there is some opposition to agricultural use because of concerns about odours and more research is needed into persistent pollutants present in sewage biosolids. Transparency of information to the public is essential for ongoing acceptance.

Jim Elser concluded the Forum by noting that **a range of initiatives are moving in the right direction** and that the Sustainable Phosphorus Alliance aims to support this by networking of initiatives and actions.

Sustainable Phosphorus Alliance Forum, Washington DC, 19 May 2017, slides online at https://phosphorusalliance.org/events

Newtrient's manure management technology catalogue

Newtrient is a new technology and social innovation company established by US dairy industry leaders to improve the sustainability of manure nutrient management, with the aim of converting manure from a problem for farmers into an economic opportunity. Its members represent over half of total US milk production.

The **online catalogue of manure nutrient management technologies and suppliers** aims to provide information to dairy farmers and their advisors, but also to facilitate and accelerate development of promising technologies by working with selected suppliers to incubate, test and pilot implement technologies.

Newtrient's objective is to assess all manure processing and nutrient recycling technologies, including anaerobic digestion, nitrification-denitrification, solids-liquids separation (centrifuge, screw-press, air flotation and others), composting, thermal processes and recovery of energy, bedding, fibres or nutrients (phosphorus recovery, ammonia stripping …). **250 were examined, and 180 identified as currently operating in the North American market and are included in the searchable catalogue**. Of these, 60 specifically address nutrient recovery.

For each company and technology, information scoring is provided on nine aspects covering commercial viability, economic & industry value and transparency & interaction:

- **Commercial viability**: operational history, operational reliability and market penetration
- **Economic and industry value**: capital cost, operations and maintenance cost, value proposition (economic, environmental and/or social benefits delivered to farm)
- **Transparency and interaction**: vendor information sharing, case study provided, customer reviews

Newtrient **labels some of the suppliers/technologies as "Recognised"** (scoring high marks on the nine technology criteria and about which Newtrient is comfortable with what the technology does what it claims to do) or "Emerging Technology" (identified as promising and heading in the right direction).

Newtrient online manure technology catalogue: www.newtrient.com/Catalog/Technology-Catalog

Meet Steve Rowe of Newtrient at ManuREsource 27-28 November to discuss extension of this catalogue of manure processing technologies and suppliers to Europe.

Recycled fertilisers

UK assessment of targeted phosphorus fertilisation

The Sustainable Arable LINK project brought together 17 partners in the UK from research, government (DEFRA) and industry, to see whether new phosphorus fertilisation approaches could "feed the crop, not the soil". Results confirm the possible benefits, but do not clearly identify ways of achieving better crop phosphorus fertiliser efficiency and reduced environmental losses whilst also maintaining crop productivity.

The current UK phosphorus fertiliser use strategy (DEFRA Fertiliser Manual RB209, 2010) is essentially 50 years old, and is based on using soil phosphorus tests to adjust fertiliser application to the estimated soil capacity to supply phosphorus to the crop: "***feed the soil, to feed the crop***" – see Withers et al. 2014 *http://pubs.acs.org/doi/pdf/10.1021/es501670j* This replaced a previous, even less efficient strategy relying only on fertiliser input to supply crop needs.

Soil phosphorus related to environmental losses

This work included two field studies and a meta-analysis of published data which showed direct relationships between soil Olsen P and dissolved phosphorus in surface run-off and drain water – see Withers et al. 2016 *http://iopscience.iop.org/article/10.1088/1748-9326/aa69fc?pageTitle=IOPscience*: a reduction of Olsen P from 25 to 10 mgP/kg (or from soil P Index 2 to 1) could significantly help address EU Water Framework Directive water quality objectives, as well as bringing economic savings in lower fertiliser consumption. About **80% of UK arable land is estimated to be at P Index 2 or higher**.

Ten field experiments at sites with low soil phosphorus showed that soil phosphorus alone could still provide 42 – 100% of crop needs (median 84%), but that crop response to conventional mineral phosphorus fertiliser (TSP triple super phosphate) was low (only 4% of applied phosphorus taken up), presumably because the **fertiliser P was being held in soil**.

Effectiveness of struvite

The best way to enhance initial use of fertiliser phosphorus by the crop was to use struvite (slower release fertiliser), applied close to the seed (enabling an initial uptake of up to 10%). Struvite was particularly effective in this way for potatoes. Also, a simulated rain storm event caused 25% loss of fertiliser phosphorus for TSP, but **no loss of phosphorus from struvite**.

Pot tests looked at foliar phosphorus fertiliser application, phosphorus containing seed dressings and use of struvite granules (slow release), showing positive results for all three. Seed inoculation with *Bacillus amyloliquefaciens FZB42* increased root development but reduced phosphorus uptake in low-P soils.

Two field trials with low to very low soil phosphorus (Index 0 – 2) showed no detectable benefit of foliar application or seed dressing, whereas grain production increased by around 2 t/ha if soil P was increased to Index 2.

Modelling of the phosphorus interactions between fertiliser, soil, root, shoot and crop yield suggested that AVAIL® treatment of conventional fertiliser (TSP) could be effective. AVAIL® is a **maleic-itaconic co-polymer, used as a coating for fertilisers**, and designed to compete for adsorption on soil particles and counteract ions in soils which immobilise phosphorus by generating insoluble precipitates. However, this treatment showed no consistent benefits when tested in pot or field trials.

Four phosphorus "run down" sites, with initial soil P Index, where fertiliser application was stopped, were monitored for 5-6 years. This demonstrated that **arable crops can exploit soil-stored phosphorus over a few years, without significant loss of productivity nor – surprisingly – of soil phosphorus status**, but also demonstrated uncertainties in determination and interpretation of soil test phosphorus.

No solution to date

The project concluded that **the current strategy of "*feed the soil, to feed the crop*" should be maintained for the present**, because no adequate solution for ensuring crop productivity without input of fertiliser phosphorus at this level could be demonstrated. However, research into possible methods to effectively "feed the crop, not the soil" should be intensified, because of the environmental (reduced phosphorus losses), resource efficiency and economic potential this could offer.

Further research into ways to "***feed the crop, not the soil***" should include machinery for fertiliser placement, chemistry to inhibit soil sorption, foliar P application, micro- and macro-germplasm to improve phosphorus uptake.

Costs of phosphorus inefficiency

The **current use of highly-soluble conventional mineral phosphate fertilisers is not optimal**, because the phosphorus is largely used to build soil P reserves rather than to feed the crop: dependence of crop production on this soil phosphorus store is estimated to cost 1-2% of the value of cereal production. Industry initiatives to improve phosphorus fertiliser efficiency should be monitored through both soil test phosphorus and analysis of crop phosphorus.

Routine crop phosphorus analysis, in addition to soil analysis, is recommended, because measurement errors are lower for crop P analysis. A "critical" phosphorus content in whole shoot biomass is 0.25% for most UK crop species, whereas the standards for interpreting phosphorus content of harvested biomass (grains, tubers) need to be redefined.

Farm phosphorus management should integrate **soil P analysis, P analysis of leaf tissues and harvested biomass, recording of yields, and phosphorus accounting** including logging all inputs in fertiliser, manures and other amendments.

"Improving the sustainability of phosphorus use in arable farming – 'Targeted P' ", AHDB (Agriculture and Horticulture Development Board), UK, project report n° 2017/2, November 2016, 195 pages
https://cereals.ahdb.org.uk/media/1231586/pr569_final_project_report.pdf

Attitudes to innovative fertilisers

A survey of fertiliser producers, distributers and farmers in Germany assessed knowledge level, attitudes and obstacles to uptake of three fertiliser eco-innovations: stabilised nitrogen fertilisers, fertigation, fertilisers from secondary raw materials.

An initial series of interviews (8, fertiliser producers and distributors) and data analysis identified a number of **eco-innovations** in fertiliser use in Germany: GMOs, strip-till, in field precision fertilisation, foliar fertilisation, use of biogas digestates, stabilised nitrogen fertilisers, fertigation, and fertilisers from secondary raw materials. The first four were excluded because considered controversial in society or because requiring change of the full agricultural system.

Stabilised nitrogen fertilisers cover three different systems: coatings which lead to controlled nitrogen release, use of a less soluble form of nitrogen and addition of a nitrogen mineralisation inhibiting chemical. SNFs have been shown to reduce nitrogen leaching and atmospheric emissions and to improve nitrogen use efficiency, but to date only represent 8-10% of nitrogen fertilisers used in Europe and 1% in the USA.

Fertigation is the application of soluble fertiliser via irrigation water. Because the nutrients are soluble and immediately plant available, application can be precisely adapted to plant needs.

The second series of interviews covered 57 fertiliser producers (12), distributers (34) and farmers (11), corresponding to replies received from a total of 250 questionnaires sent out.

Results show that **farmers are the group most sceptical towards fertiliser eco-innovation**, whereas the fertiliser supply chain actors mostly take environmental aspects into account in their business strategy. Both farmers and suppliers however consider that legal regulations, in particular through the Common Agricultural Policy, will drive environmental requirements and eco-innovation.

Whereas stabilised nitrogen fertilisers are well known by both farmers and the supply chain, **fertilisers from secondary raw materials are known by around 60% of fertiliser manufacturers and only 30% of distributers and farmers**.

The authors note that **a key obstacle to eco-innovation uptake by farmers is cost**. They conclude that eco-innovation is currently motivated by technological push rather than market pull, but that this could be improved by: further implementation of regulatory requirements (for example limitation of farm nutrient surpluses), promoting market pull from consumers and supermarkets (eco-marketing), and improving farmers' knowledge through information.

European Commission Science for Environment Policy, issue 477, 18/11/2016 "How to increase the uptake of environmentally friendly fertilisers in Germany" http://ec.europa.eu/environment/integration/research/newsalert/pdf/how_to_increase_uptake_environmentally_friendly_fertilisers_germany_477na3_en.pdf *and "Drivers for the Adoption of Eco-Innovations in the German Fertilizer Supply Chain", Sustainability, 8(8): 682, 2016*
http://dx.doi.org/10.3390/su8080682

K Hasler (1), H.-W. Olfs (1), O. Omta (2), S. Bröring (3). 1 = University of Applied Sciences Osnabrück, Am Krümpel 31, Osnabrück 49090, Germany; 2 = Management Studies Group, Wageningen University, Hollandseweg 1,Wageningen 6706 KN, The Netherlands; 3 = Institute for Food and Resource Economics, University of Bonn, Meckenheimer Allee 174, Bonn 53115, Germany s.broering@ilr.uni-bonn.de

Health and safety

Ecotoxicity of fertilisers and potassium monophosphate

Worldwide, fertiliser use is some 104 million tons N, 41 million tons P_2O_5 and 27 million tons K_2O (IFA *2013*). Although these nutrients occur naturally, it is therefore also important to assess their ecotoxicity, both when combined as fertiliser compounds as sold commercially and as separate pure mineral salts. This study tested their ecotoxicity on aquatic snails and fish.

The following were **tested for ecotoxicity**:

- Commercially purchased fertilisers: potassium chloride, potassium nitrate, superphosphate, urea
- Pure chemicals: potassium chloride, potassium nitrate, urea, potassium phosphate monobasic (KH_2PO_4)

These products were tested for ecotoxicity using the benthic snail *Biomphalaria glabrata* and zebrafish *Danio rerio*. Test methods were acute toxicity (LC50 at 48 and 96 hours) according to the following methods: for aquatic snail, Oliveira-Filho 2005 and for fish Brazil NBR 15088. Concentrations tested were 75 – 3000 mg/l and 1000 – 40000 mg/l for urea, plus controls.

Results are compared with previous ecotoxicity studies on potassium chloride, potassium nitrate, urea and potassium phosphate monobasic.

Results show that **toxicity depends both on other ions present and on the organism**. For example, potassium ions with phosphate were more toxic to the snails than potassium ions with chloride or nitrate, whereas for the fish potassium ions with chloride were more toxic.

Nitrogen was more toxic as ammonium than as nitrate, particularly for the snails which show high time intolerance at 96h with an LC50 concentration near zero

The authors conclude that **toxicity to aquatic organisms was found for the fertilisers potassium chloride potassium nitrate and urea, but not detected for superphosphate**. Of the pure chemicals, the most toxic to the snail was potassium phosphate and to the fish potassium chloride.

"Comparative Analysis between Ecotoxicity of Nitrogen-, Phosphorus-, and Potassium-Based Fertilizers and Their Active Ingredients", Toxics 5-2-2017. dx.doi.org/10.3390/toxics5010002

N. de Castro Soares Simplício 1,2,3, D. de Freitas Muniz 1, F. Moreira Rocha 2, D. Cavalcanti Martins 2, Z. Barreira Dias 3, B. da Costa Farias 2, E. Oliveira-Filho. 1 Embrapa Cerrados, Rodovia BR 020, Km 18, Planaltina DF 73310-970, Brazil;2 Faculdade de Ciências da Educação e Saúde (FACES), Centro Universitário de Brasília (UniCEUB), Brasília DF 70790-075, Brazil; 3 Faculdade UnB Planaltina, Campus de Planaltina Área Universitária 01, Universidade de Brasília (UnB), Planaltina DF 73345-010, Brazil; eduardo.cyrino@embrapa.br

New book on phosphorus food science

A new Springer/Humana book, edited by Gutiérrez, Kalantar-Zadeh and Mehrotra brings together and summarises global up-to-date knowledge on clinical impacts of phosphorus in food, both natural food phosphorus content and phosphate food additives, looking at phosphorus metabolism, links to health and interactions with other nutrients in food.

Orlando Gutiérrez, University of Alabama at Birmingham, AL USA, introduces with a short history of phosphorus (see also for information "The Shocking History of Phosphorus", Elmsley, in SCOPE Newsletter n°42). He emphasises the importance of clearly distinguishing between phosphorus and phosphate, noting that often soluble inorganic phosphate (P_i) is measured rather than total P because this is easier. He underlines that large scale societal use of phosphorus has only developed over the last 150 years, and that **understanding of phosphorus in biological systems is still fluid and continues to evolve**. He concludes by noting that urbanisation has resulted in society's phosphorus use becoming increasingly linear, resulting in both environmental impacts (eutrophication) and in concerns about consumption of non-renewable resources of rock phosphate, with a need to today both moderate P use in the food chain and develop recycling.

Body phosphorus metabolism

Keith Hruska, Washington University, MO USA, provides a **summary of phosphorus homeostatis in the body**. He notes that blood (serum) P levels of 2.5 – 4.5 mmol are considered "normal", with a diurnal variation of 0.6-1 mmol and the lowest levels showing in the morning (8h – 11h). Over 85% of serum P is soluble inorganic phosphate, and a small part is protein-bound.

Dr Hruska summarises the **mechanisms of phosphorus absorption in the intestine**, indicating that around 70% (net) is absorbed by the body (80% absorbed but 10% returned to the gut in digestive juices) and 30% is found in faeces. Gut P absorption occurs mainly in the duodenum and jejunum, partly by passive mechanisms, whose rate is proportional to diet phosphorus content, and mainly by active mechanisms [rate of transfer across the intestinal brush-border epithelial membrane involving a sodium-phosphate cotransport system NaPiIIbNpt2b/SLC34A2)], whose rate is controlled by hormones.

In addition to this control of P intake, **body phosphorus levels are principally controlled by kidney excretion and reabsorption**. Around 7gP/day is filtered out by the kidney and 80-90% of this is then reabsorbed by the kidney renal tubules, resulting in equilibrium to gut intake. Dr Hruska summarises current knowledge of the physiology and mechanisms of P resorption in the kidney, which (as in the gut) is mainly by active mechanisms involving sodium-phosphate cotransporters (types I, II and III). These co-transporters are controlled by a complex combination of factors including para thyroid hormone (PTH), fibroblast growth factor FGF23 (and klotho), atrial natriuretic peptide, nitric oxide, signallers and activators (such as PK-A, PK-C, PK-G, ERK 1/2, PDZ domain and ERM proteins). The biology of PTH and FGF23 and phosphate homeostasis control are discussed.

Syed Rafi and **Mohammed Razzaque** review current knowledge concerning **hormonal regulation of phosphorus homeostasis**, in particular the roles and interactions of parathyroid hormone (PTH), fibroblast growth factor (FGF23) and Klotho cofactor (membrane protein). FGF23 produced in the bone increases renal excretion of phosphate (by suppressing Na/Pi cotransporters, through Klotho) and reduces intestinal absorption of phosphorus (by reducing vitamin D production). PTH also suppresses Na/Pi cotransporters in the kidneys, but increases vitamin D production and also mobilises phosphorus from bones into the bloodstream.

Other hormones influencing phosphorus metabolism cited include growth hormone, insulin, thyroid hormone (which reduce kidney P excretion) and atrial natriuretic factor, calcitonin, glucocorticoids (increase excretion). The authors conclude that recent experiments have demonstrated that kidney phosphorus homeostasis is controlled by a limited number of factors, suggesting that better understanding of FGF23 and Klotho and data on serum FGF23 levels may enable better definition of clinical treatments (e.g. vitamin D therapy in dialysis) or prediction of clinical risks.

Bross, Shah and **Kopple** summarise the **role of phosphorus in nutrition**, noting that phosphorus (P) represents around 1% of body weight, and that around 85% of the body's phosphorus is stored in bones and teeth. Extracellular fluids contain only around 0.1% of total body phosphorus. Serum phosphorus levels are presented as normal in the range 2.5-4.5 mmol/l (higher for infants 4.5-8.3 mmol/l)

The **different dietary recommendations** are explained and presented for phosphorus:

- **EAR** (estimated average requirement) = median intake needed to meet dietary requirements
- **RDA** (recommended daily allowance) = level sufficient to meet dietary requirements of nearly all of the population
- **AI** (adequate intake) = recommended average daily intake
- **UL** (tolerable upper intake level) = highest intake likely to pose no adverse health impacts to nearly all of the population

Phosphorus in diet and health

Mona Calvo and **Jaime Uribarri** discuss **phosphorus levels in modern diets**, noting **likely underestimation of these levels** and suggest that P-content labelling of processed foods should be developed. They note that **further research is needed into possible health questions**: to establish whether or not phosphorus levels in the diet, in particular bio-available P in food additives, may contribute to risk of cardiovascular disease (CVD), bone weakening (osteoporosis) or kidney disease in the general population. They suggest that **principal measurable sources of P in today's diet in the USA are milk and dairy products (c. 21%) and meat based products (c. 18%).**

They explain that **labelling of total phosphorus content in foods is often absent**, added phosphorus as food additives must be listed - but not quantified - on the label and if present can be expressed in different ways (e.g. as % of Daily Value or by listing in the ingredients label); however, the labelling rarely lists the actual phosphorus content of the food. Better information about phosphorus content of different foods is very important for kidney disease (CKD) patients

They note that the US National Academy of Sciences Institute of Medicine has established EAR (Estimated Average Requirements) for phosphorus at around 0.4-

0.6 g P/day for adults and children, with a higher level of just over 1 g P/day for teenagers (actively growing bone). Diet P intake estimated by NHANES (US National Health and Nutrition Examination Surveys) that uses measurable P content of food but not added P, is however 2-3 times the EAR levels for adults and children. The authors reference several recent papers addressing **changes in P additive use and changes in eating patterns**, as well as increases in sales of processed meats or use of phosphate modified starches in frozen foods all of which support the idea that current intakes from NHANES considerably underestimate total P intake. Without information about the contribution of P from the use of food additives, NHANES and other surveys may underestimate intakes of diet P by up to 30%. They note that further research is needed to assess to what extent phosphorus in phytate (e.g. in grains, nuts, pulses and other plant sources) is available for uptake in humans. Plant sources of P such as phytate are less bioavailable compared to the natural P from meat and milk and the highly bioavailable P from P-containing food additives.

The authors provide details of the **different uses of phosphate food additives**, noting that they "contribute in many ways to the overall quality, safety, nutritive value, taste appeal, convenience and economy of foods", that they have been assessed by responsible authorities (1975-80 GRAS Committee, EFSA) and considered to be safe, subject to ensuring that the calcium:phosphorus dietary intake balance is maintained. The authors argue that this balance has not been maintained due to the increased consumption of convenience foods processed with P-containing additives, with intake of P exceeding nutrient requirements and calcium intake that often fails to meet the calcium EAR. They conclude by calling for labelling of phosphorus content of food, as this is important at least for kidney patients, of whom there are now over 26 million in the USA.

Ketteler summarises the apparent link between elevated serum phosphate levels and **cardio vascular disease (CVD)** indicated by a number of large general population epidemiological cohort studies. He notes that ar**ound 7% of adults suffer from kidney disease (CKD)**, and that in advanced CKD increased serum phosphate is linked with cardiovascular calcification, left ventricular hypertrophy and failure and overall CVD mortality. Increased serum phosphorus is thought to lead to "osteochondrogenic transdifferentiation" of vascular smooth muscle cells, resulting in bone-like modification of the artery wall (arterial calcification) and so reduction of elasticity of arteries. The ascending aorta and its arch are elastic tissue which stretch during systole, restoring energy in diastole, so reducing left ventricular heart muscle effort.

Arterial calcification is related to expression of bone-specific proteins (osteopontin, alkaline phosphatase, osteocalcin, collagen-1) and possibly also to morphological changes in nano-scale calcium – phosphate – protein particles (CPP) in artery wall cell vesicles, from spherical to elongated crystal forms.

Phosphate-related arterial calcification was first shown in vitro by Jono 2000 and occurrence was shown in humans by Moe 2002. Anderson and Depster discuss the role of dietary phosphorus in bone health, underlining the need to ensure an appropriate balance between calcium and phosphorus intake ($0.5 < Ca:P < 1.5$), **underlining the roles of FGF23 and PTH (parathyroid hormone).**

Phosphorus and health in kidney disease

Takeda, **Yamamoto** and **Taketani** also discuss **phosphorus in diet and health**. They note that phosphorus in meat and food additives is easily absorbed in the gut, phosphorus in dairy less easily (20% of P in milk is in casein) and phosphorus in plant products much less well (phytate). A table of energy, protein and phosphorus content of some 70 different foodstuffs is provided.

The authors reference a number of studies relating dietary phosphorus intake to both mortality and cardio-vascular disease (CVD) in both dialysis-dependent and less advanced kidney disease patients (CKD), and relating serum phosphorus in the general population to risk of CVD, but indicate **no evidence that diet phosphorus is related to CVD in the general population**.

Jovanovich and **Chonchol** discuss abnormalities in **phosphorus metabolism related to kidney disease**, noting the resulting increased levels of FGF23 and parathyroid hormone and modified vitamin D metabolism, so impacting bone phosphorus metabolism and gut phosphorus uptake. The links between these factors and CVD risk for kidney patients needs further research.

Beck discusses possible **links between serum phosphorus, related hormones and cell development**. Serum phosphate can stimulate growth or development of both healthy or tumour cells. Studies show that both low and high phosphate levels can influence initiation or development of cancer cells, and further studies are needed on this question.

Gutekunst discusses the **significance of phosphate food additives for kidney disease patients**. She cites Leon et al. 2013 who analysed 10 selected food products, estimating that those containing phosphate food additives could increase diet phosphorus intake by 0.7 gP/day, and that these were generally cheaper products. She notes that food products with high phosphate additive content may be more frequently consumed by low socio-economic status communities in which CKD is more prevalent. Like Calvo and Uribarri above, the author refers to studies showing that diet table indications of phosphorus content of food products can be inaccurate, e.g. (Sullivan 2007) 90% of 38 chicken products had phosphorus levels >10% different, either higher or lower, than ESHA FP SQL database figures. She underlines the difficulties posed for both advanced and early-stage CKD patients by inaccurate information on phosphorus content of foodstuffs.

Functions of phosphate food additives

Lampila and **McMillin** present the **different uses of phosphorus food additives, including the chemical formulas, pH and solubility of 24 sodium, calcium, potassium, magnesium and aluminium phosphate salts**. Functions in food processing include: pH adjustment, protein dispersion in meat products (frankfurter, bolognas), coffee whitener buffering, moisture absorption in spices (ensuring free flow), process cheese (ion exchange enabling flow, even melt and spreadability), colour conservation in potato products (prevent iron mediated black colour), whipping and stability of egg whites, ice creams and foams, and texturing and leavening of baked goods and flavouring of cola drinks. Phosphate salts are used to raise the temperature of heat denaturation in meat, contributing to palatability by preventing water loss (both due to post mortem changes in muscle tissue and in cooking) and enhancing microbial safety (carcass washes). Phosphate salts reduce nitrites (and so nitrosamines) compared to sodium salts (brine) via alteration of pH.

Phosphate salts (including STPP) are also used to enable quality processing and maintaining quality of **seafood products**: they can reduce moisture loss in seafood products (which otherwise occurs more rapidly than in meats), improve separation of flesh from crustacean shells in processing during mechanical peeling after steam cooking and ensure cryoprotection (prevention of chemical damage to proteins during freezing) and prevention of crystal formation (struvite) during canning.

Overestimations of food additive phosphate consumption

Lampila and McMillin note that **food-grade phosphates are also used in a range of other applications and that in some cases this leads to an overestimation of the amounts actually used in consumed food, and so of dietary intake estimates**. These other uses include

- **food processing applications where the phosphate does not end up in the final product**, e.g. carcass washing and other food product cleaning, shrimp peeling, sugar refining, lard rendering, scale removal in dairy and beverage factories …
- **non-food applications**: cosmetics, toothpastes, mouthwash, bowel evacuants, pet foods, yeast nutrient, tobacco products (burn control)
- **food-contact chemical products** (polymers, adhesives, Styrofoam polymerisation …)
- **industrial applications** using high-grade phosphate products: photocopier toner, metal finishing, lubricants

They further suggest that a number of studies have employed faulty methods to assess total phosphorus or have made assumptions that phosphorus is present in food ingredients. For example, in the USA only three food-grade phosphates and three methods using phosphorus oxychloride are permitted in the modification of starch. There are 30 other chemical methods permitted to modify starch as well as physical methods. Other studies imply that phosphates are used liberally when, in fact, they are self-limiting due to the potential for off-flavour development when used in excess.

Other chapters of the book loot at phosphorus use in livestock production, measurement of phosphorus in foodstuffs, phosphorus and bone health, dietary phosphorus deficiency risks, and interactions between dietary phosphorus and other minerals.

"Clinical aspects of natural and added phosphorus in foods", Humana Press (Springer), 260 pages, O. Gutiérrez, K. Kalantar-Zadeh and R. Mehrotra, editors. For affiliations of authors cited, please see the book itself.
www.springer.com/us/book/9781493965649

Ecotoxicity of recycled phosphate products

Three different struvites recovered from sewage sludge and five phosphate products recovered from sludge incineration ash were analysed for contaminants (organic and heavy metals) and tested for ecotoxicity (to aquatic plants, aquatic invertebrates, earthworms), with comparison to Triple Super Phosphate fertiliser. Leachates were also tested for ecotoxicity. The results were compared with a quantitative and relative risk assessment (Kraus & Seis 2015) conducted with single pollutants contained in the products.

The **three struvites were precipitated from municipal sewage sludge** (a) after digestion before dewatering (b) after digestion after dewatering (c) without digestion after sulphuric acid dissolution. The five thermal recovered phosphate products were raw sludge mono-incineration ash, $MgCl_2$ and Na_2CO_3 calcination recovered P, metallic P slag and CaP/struvite precipitated after acid leaching of ash. Triple Super Phosphate (TSP) was purchased from Van Loon Hoeven B.V. (NL).

These nine products were analysed for **heavy metals** and the three struvites were analysed for six **organic contaminants**:

- Benzotriazole – anticorrosive
- Carbamazepine – pharmaceutical (anticonvulsive)
- Diclofenac – pharmaceutical (analgesic)
- Estrone – hormone
- Mecoprop –pesticide (herbicide)
- Sulfamethoxazole – pharmaceutical (antibiotic)

Benzotriazole, Carbamazepine and Diclofenac were detected in all three struvite samples at 1 – 113 ppb dry matter. Estrone, Mecoprop and Sulfamethoxazole were below detection levels in all three struvites. Metals analysed were lower in the struvites than in TSP, except for copper, iron, lead and mercury. Metals in the thermal recovered phosphate varied considerably.

Ecotoxicity tests

Ecotoxicity of the nine products, and also of copper chloride as reference, was tested using:

- **Chronic growth inhibition to duckweed** (*Lemna minor*), test method ISO 200279, at five concentrations from 0.01 to 10 g DM/l
- **Acute toxicity and behavioural measurements with the aquatic invertebrate amphipod** *Gammarus fossarum*, test method US EPA Gammarid Acute Toxicity Test with adjustments, at five concentrations 0.005 – 5 g DM/l)
- **Avoidance test with earthworms** *Eisenia fetida*, test method ISO 17512-1 with adjustments, at five concentrations 0.05 – 5 % by dry weight in soil/compost.

Additionally, **simulated leachate** obtained by DIN 12457-1 (shaking 250 g DM of product in 0.5 l water for 24 hours at 20°C) was tested for toxicity on the gammarid as above, at dilutions of 0.001 – 1%. This was done for TSP and for the most recycled phosphate product with the most effect in the direct assessment. NOEC/LOEC (No/Lowest Observed Effect) concentrations were derived.

The authors note that **TSP showed higher ecotoxicity at the higher concentrations tested**, probably due to higher water solubility. The struvites however resulted in higher earthworm avoidance behaviour at lower concentrations: the authors consider that this may be due to the organic contaminants.

They conclude that agronomical relevant application levels of all of the recovered phosphate products and of triple super phosphate (TSP), in the worst case scenario, are **unlikely to have acute toxic effects on earthworms**, that **the recovered phosphates might have a small impact on aquatic plants** and **TSP some negative impact on aquatic amphipods**.

Overall, the authors conclude of the ecotoxicity with regard to the relative risk assessment (Kraus & Seis) that **the recovered phosphate products, in particular struvite, showed to be of high quality and low hazard**, and should be considered for agricultural phosphorus fertilisation.

"Ecotoxicological Assessment of Phosphate Recyclates from Sewage Sludges", Water Air Soil Pollut (2017) 228:171
http://dx.doi.org/10.1007/s11270-017-3331-7

N. Rastetter, A. Gerhardt, LimCo International GmbH, Wollmatinger Str. 22, 78467 Constance, Germany almutg@web.de
N. Rastetter, K. O. Rothhaupt, Limnological Institute, University of Konstanz, 78464 Constance, Germany nadja.rastetter@uni-konstanz.de

France conference on phosphorus recycling in agriculture

A first French national meeting on recycled phosphorus in agriculture, supported by the Agriculture Ministry, with participation of the French Environment and Finance Ministries, identified national expertise in organics recycling and secondary materials standards, and a need for policy leadership and regulatory developments.

The one-day conference on "***Recycled phosphorus in agriculture: secondary resources, products, quality, regulation***", co-organised by COMIFER (French national committee on rational fertilisation) and ESPP, with the patronage of the Ministry for Agriculture Food and Forestry, took place on 11th April 2017, at the prestigious agricultural training centre *AgroParisTech*, with over 150 participants from farming organisations, regulators and policy makers, fertiliser industry and distributors, science and agronomy, stakeholders and media.

The meeting was opened by **Christine Le Souder, Arvalis (French arable crops R&D institute)** and **President of COMIFER**, with the objectives of day: to identify questions and opportunities for recycled phosphorus use in agriculture, as a key component of the circular economy.

Chris Thornton, ESPP (European Sustainable Phosphorus Platform), explained why phosphorus stewardship is important. Phosphate rock is a non-substitutable, limited resource, for which Europe is largely dependent on imports. Prices are linked to global food prices and supplies are geographically concentrated, leading to potential instability. At the same time, phosphorus and nitrogen are identified as key factors exceeding "**Planetary Boundaries**" (see SCOPE Newsletter n°*103*) and phosphorus is the most frequent (non morphological) reason why rivers and lakes are failing to achieve **EU Water Framework Directive** quality objectives. This has led to recent developments in EU policies, in particular inclusion of phosphate rock on the list of 20 **EU Critical Raw Materials** (see SCOPE Newsletter n°*104*) and inclusion of nutrients in the EU's Circular Economy policies. The **proposed new EU Fertilisers Regulation** (currently in the final decision process) will take this forward, by opening the EU market for recycled nutrient products and thus also for nutrient recycling technologies.

ESPP showed a **selection of success stories** where companies are already recycling nutrients, including from manure, sewage, slaughterhouse wastes. He noted that France has in the past been condemned for failure to implement EU legislation on nutrients (Nitrates Directive, Urban Waste Water Treatment Directive) but that the Circular Economy now offers positive opportunities for synergies between environmental improvement, farmers' income, rural jobs and new technology business.

Fertilising residual materials (MAFOR)

Patrick Dabert, IRSTEA, presented the conclusions of the **French collective expertise (ESCo) on the use of organic fertilising residual materials (MAFOR) in agriculture and forestry**, produced jointly by INRA, CNRS and IRSTEA for the Ministries for Agriculture and for the Environment in 2014 (see SCOPE Newsletter n°*109*). France produces nearly 400 Mt/year (wet mass) organic wastes (livestock, households, industry, not including on-farm crop by-products). Around 300 Mt are livestock manures/slurries, of which 250 Mt bovine and 50 Mt other livestock. Around half of the manure produced falls directly onto fields, the remaining half is mostly applied to farmland. Overall, nearly 95% of the collected organic wastes are recycled in animal feed or composting or other agricultural land application routes. representing nearly 210 ktP/y (480 kt P_2O_5), compared to around 230 ktP/y (530 kt P_2O_5) applied in commercialised organic and mineral fertilisers. He identified as **obstacles to effective recycling of organic wastes**: geographic concentration of sources, physical parameters making transport difficult (in particular water content), reaction with other elements rendering phosphorus poorly crop available (e.g. iron in sewage sludges using chemical precipitation), economic and environmental costs especially for sites with low amounts of waste.

In discussion, participants noted that spreading of organic residual materials to land (e.g. sewage sludge or manures) is cost effective but does not necessarily mean effective recycling, for example if application rates exceed crop needs for phosphorus, or if cows are drinking in water courses resulting in manure going directly into surface waters so causing pollution rather than fertilising land.

Agronomic value

Christian Morel, INRA, outlined the qualities of organic fertilising residual materials (MAFOR), discussing phosphorus availability, physical form and contaminants. He underlined that their **agronomic value is related to the nutrient content (N, P, K, other nutrients and micro-nutrients), and also as a soil amendment (organic carbon, liming).** The societal value of their application should also take into account: carbon storage in soil (climate change mitigation), substitution of primary mineral fertilisers and upstream bio-energy production (methane). However, they must be safe (contaminants), adapted to farmers' requirements (spreading), must not emit ammonia in storage or use, and face challenges concerning geographical separation of production and use and regulatory obstacles.

He summarised **long-term field studies** showing that, after 13 years application to crops of different MAFOR (composts of different organic wastes, cow manure sewage sludge), with different phosphorus contents and P/C ratios, had differing impacts on soil phosphorus and soil carbon (Houot et al: Innnovations Agronomiques, *2009*, vol. 5, pp. 69-81 ; Agriculture, Ecosystems & Environment, *2016*, vol. 216, pp. 23-33 – see *www6.inra.fr/qualiagro*).

Pot trial and field trial data suggest that **raw biological P-removal sewage sludge, agricultural digestate, pig manure and poultry litter and struvite show phosphorus availability similar to that of triple super phosphate** in acid to neutral soils, and so can substitute to the use of mineral phosphate fertiliser. However, some MAFORs (e.g. certain biochars or sewage sludge incineration ashes) may contain poorly-available forms of phosphorus (such as amorphous calcium phosphates or apatite).

Christian Morel notes that in pot trials there are reactions between MAFOR, phosphate fertilisers and soil phosphorus. **Isotopic labelling** enables to distinguish between P taken up by the plant from these different sources. He suggests that soil – MAFOR incubation tests (without plants) are also a simple method to assess plant availability of MAFOR phosphorus.

Regulatory obstacles

Loïc Lejay, French Ministry for the Environment, summarised the Ministry's current position on the regulatory status of recycled phosphate products use in agriculture. **The Ministry's concern is to ensure that recycled nutrient products are safe for health and for the environment**. He indicated that the French Ministry considers that sewage works are "principally for treating waste water" and therefore that sewage sludge and other solids coming out of the works are legally "waste". This classification as "waste" guarantees traceability and waste-producer responsibility. The Ministry indicates that this waste status for struvite is not a barrier for its further reuse, in the case where an authorized fertiliser production unit would use this struvite (still legally considered as waste when shipped from the sewage works) as an input instead of mineral phosphorous in its process. The Environment Ministry suggests that struvite may also be classified as a "by-product" if reused-treated-water itself is considered as a product or if an "End-of-Waste" dossier could be developed, but any of these routes would not exonerate from the obligation in France to prepare and submit a dossier for authorisation for use as fertiliser

Participants questioned how the Environment Ministry's vision of sewage works as "waste treatment" installations and of all recycled products produced within them as "waste" could become **compatible with a circular economy vision where sewage works are operated as energy, water and resource recovery factories**.

Bruno Canus, French Ministry for Agriculture, confirmed the **French State's objective of ensuring that recycled nutrient products are safe for farmers and for public health, for soil and for the environment**. Certain recycled materials product in France (e.g. sewage sludges) can be applied to farmland under authorised "waste" spreading plans, which ensure safety and traceability. In order to not be treated like this (as "waste"), fertiliser products must apply for authorization to be sold in France as a fertiliser product ("AMM" homologation for an individual company's specific product, delivered by the French Health and Risks Agency ANSES) or develop, by derogation, a technical dossier for submission to BN-Ferti (Fertilization standardization office) and so a NFU standard for the category of product. Both of these applications require for risk assessment by ANSES.

The **principle of "Mutual Recognition"** (by which a product allowed for sale in one EU Member State should generally be accepted in other States) could be applied to a product authorised in another country (e.g. struvite in Denmark), but a formal application with a dossier must nonetheless be submitted to ANSES before acceptance in France. Mr Canus also notes that this only applies to (in this case) struvite produced in countries in which it is legally authorised as a fertiliser category (e.g. Denmark, Netherlands), not to struvite produced in France, which must follow the procedure specified in the paragraph above.

One participant noted that these procedure are time consuming and expensive. Another participant indicated a cost of around 200 000 € for an AMM homologation, inaccessible for small volume products.

It was noted by participants that **France's NF U 44-095 and NF U 44-051 standards for composts enable composts respecting specific criteria for input materials (for NF U 44-095 this can include sewage sludges), processing, contaminant levels, etc. to be sold in France as a soil improver**. Work is currently underway to develop an NF U standard for manure digestates. The French fertiliser standard NF U 42-001-1 already authorises some ashes, and work is underway to include further types of ash in the standard NF U 44-203 for soil improvers to take into account the alkalinity value of ashes. However, these materials, authorised for sale as fertilisers or soil improvers in France, are not yet today considered to be products and work is still underway to enable End-of-Waste status.

General discussion showed that many participants consider that the time and investment necessary to obtain legal authorisation of recycled nutrient products as a fertiliser or soil amendment in France represent a significant obstacle to development of new products, markets and recycling processes. On the other hand, French NFU standards once established are exemplary, ensure quality for farmers and safety, and provide recognised and reliable market clarity once established.

It was also noted that **the situation will change significantly with the new EU Fertilisers Regulation**, when this is implemented, hopefully within around two years. Products which have obtained the CE label (e.g. CE composts, CE digestates, recovered struvite if STRUBIAS is implemented) will be then authorised in France, without any additional ANSES opinion or other dossier. France will be able to also have, as national fertiliser (cannot be sold outside France, unless the other country specifically implements 'Mutual Recognition') products which are not CE-label but which are homologated or NFU in France.

The conference included four workshops on bioavailability of phosphorus in recycled nutrient products, secondary phosphorus resources and flows, circular economy policies and contaminants.

Workshop: bioavailability of phosphorus in secondary products

Emmanuel Frossard, ETH Zurich, and **Pascal Denoroy, INRA Bordeaux,** summarised the discussion which concentrated on the effects of MAFOR (organic fertilising residual materials) on the availability and uptake of phosphorus by crops. The use of MAFOR within the overall application of good agricultural practice was considered a prerequisite in this discussion.

The group made a **plea for a structured approach to understand how the addition of MAFOR could affect P availability and uptake by crops due to the complex interactions occurring in MAFOR-soil-plant systems**. In a first step, P availability (and forms of P) in MAFOR should be assessed as well as the MAFOR's basic properties, and only then their effects in the overall MAFOR-soil-plant system. Given the diversity of MAFOR, the acquisition of additional references by research was considered essential.

The importance of indirect effects of MAFOR on P availability and uptake was emphasised, **related to their effects on e.g. organic carbon and nitrogen inputs, and on soil pH, microbiology or structure**. Consequently, the use of standard soil phosphorus tests may often not be meaningful – whereas, on the other hand, studies with radiolabelled P cannot be used in routine testing. Therefore new soil P test methods might be needed to provide appropriate information to farmers to manage fertilisation with MAFOR, e.g. using soil incubation methods. But testing must also be low-cost and rapid for farmers.

A matrix of results comparing standard soil P extraction results (in particular those referenced in regulation) to incubation tests (by region, crop, soil type …) and standardised plant experiments, organized by basic MAFOR characteristics, could provide such a tool.

Phosphorus flows and secondary resource potentials

Thomas Nesme, Bordeaux Sciences Agro, and **Sylvain Pellerin, INRA Bordeaux**, presented the discussions of this workshop which identified different **secondary resources from which phosphorus can be potentially reused or recycled**, obstacles to phosphorus recycling and progress needed to enable recycling. It was underlined the considerable differences in phosphorus flows (secondary resources and crop needs) between different regions.

For certain phosphorus waste flows, there is **significant potential to increase recycling in France**:

- **Phosphorus stored in agricultural soils**. In some regions, the stock resulting from past fertiliser over-application can be reduced without impacting productivity. At the global scale, around half the P applied as fertilising materials to cropland soils (550 kg P/ha over the period 1965-2007) has accumulated in soils.
- **Livestock manures**: efficiency of use can be improved: closer connection with crop production, avoid over-application, adapt to crop needs, appropriate timing …
- **Municipal solid organic waste**: France is behind in separate collection.
-

Obstacles identified to increasing phosphorus recycling to agriculture included in particular: regulatory complexity and lack of clarity in defining legal responsibilities, lack of farmer confidence in the nutrient value of organic products (less knowledge about phosphorus in secondary materials than about nitrogen), concerns about contaminants, costs and logistics of collection and recycling, including geographical distances and transport.

The workshop proposed a number of **areas for possible actions**:

- Options for flexibility in regulation
- Clarifying legal responsibilities between producers and regulators
- Data base on characteristics of secondary nutrient materials
- Standards for recycled nutrient products
- Regional nutrient recycling policies
- Re-linking livestock production and arable crops
- Nutrient circular economy investment policy
- Structuring of sectors such as municipal organic/food wastes, digestates
- Reduce phosphorus losses, e.g. soil erosion, improving animal feed efficiency
- Science research: P availability in soil, P-efficient crop strains
- Farmer outreach: revising fertilisation practices “feed the crop not the soil”
- Economic and Life Cycle Assessment of pilot nutrient recycling projects

Nutrient circular economy

Christine Le Souder, Arvalis, and **Benjamin Balloy, Permanent Assembly of Chambers of Agriculture**, summarised conclusions of this workshop which emphasised **the importance of economic, communication – image and regulatory issues for developing the nutrient circular economy**.

New policies may be needed to enable nutrient recycling to achieve profitability or to facilitate investments, and these need to be harmonised across European countries. Innovation should be supported, and the idea of inter-country actions to facilitate emergence of a market of innovative products or processes was proposed – the example of the **North Sea Resources Roundabout** was cited (see SCOPE Newsletter n°*120*).

One immediate proposal is to integrate recycling, carbon impact and life cycle analysis into Public Procurement criteria. **Communications actions are needed**, targeting decision makers, local authorities, users and stakeholders, to develop a positive image of nutrient recycling and ensure acceptance of recycled nutrient products based on “wastes”.

A number of **regulatory issues** were raised:

- In order to facilitate innovation in new recycled nutrient products, dispositions enabling **temporary market authorisation** should be enlarged to cover not only research/testing but also initial implementation
- Nutrient recycling **investments should not be treated as Nitrates Directive 'conformity' costs** for manure treatment (this excludes from Water Agency subsidies)
- **Manure use plans** required under the Nitrates Directive (in Vulnerable Zones) are too complex, inciting farmers to prefer to use mineral fertilisers

Jean-François Gaillaud, Ministry of Finance, noted that the "**France Expérimentation**" regulatory tool is *currently* being used to allow testing of re-use of treated water from sewage works. The objective is that the derogatory criteria developed in the full-scale testing will then be transferred into adaptation of regulations. He also cited the **2015 law on Energy and Green Growth** (Loi 2015-992 du 17 août 2015) *which* promotes the circular economy and includes dispositions on reducing food waste, improving separate collection of organic wastes and updating waste regulation.

Contaminants in secondary materials

Florence Catrycke, UNIFA Union des industries de la fertilisation, and **Chris Thornton, ESPP**, summarised this workshop. The range of participants, including farmers, regulators, industry and environment NGO France Nature Environnement, showed that agricultural application of sewage sludge today is seen as positive, for the environment and for the economy, but that there are concerns about contaminants and a perceived lack of information about these.

Heavy metal contaminants are considered known and increasingly controlled, but a complex variety of other possible **contaminants are of concern**: pathogens including plant diseases, organic contaminants including pharmaceuticals, nanoparticles, and micro-plastics.

Information about contaminants in sewage sludge is considered insufficient concerning

- Organic contaminants in sludge (more information about these in the water phase)
- Impacts on soil biology
- Antibiotic resistance in soils
- Risk analysis
- Ecotoxicity of combination of contaminants in sludge
- How and what to analyse
- Effectiveness of treatment processes in reducing pharmaceuticals in sludge

The importance of **upstream action to reduce contaminant inputs** to sewage was emphasised, including reducing use of pharmaceuticals (France consumes high levels of antibiotics, antidepressants), source separation in hospitals, development of less persistent pharmaceutical molecules. However "zero contaminants" is not possible, so it is important to develop, in dialogue with different societal stakeholders, a balance between nutrient recycling – safety and costs.

Mathieu Delahaye, Suez, underlined the importance of **assessing contaminants according to application to land** (per kg nutrient) in order to reach meaningful conclusions on risk and safety.

Panel discussion

The conference concluded with a panel discussion:

Valérie Maquère, Agriculture Ministry, underlined that the 2015 French *law* on Energy and Green Growth requires (art. 110-1-2-4) to "*increase the quantity of waste which undergoes material valorisation, particularly organic … to 55% in 2020 and 65% in 2025 (by mass)*". France's bioeconomy *strategy* 2017 refers to **digestates as a route to reduce dependency on mineral fertilisers**. The nutrient circular economy is an important opportunity for agricultural businesses and for the environment. However, **ensuring quality and safety must be the priority**, to ensure food security and protect soil quality. There is a need for work together between the different concerned French Ministries.

Jean-Philippe Bernard, Charente Maritime Chamber of Agriculture, considered that farmers are positive towards the development of the bio- circular economy. This will **require moving beyond the current image difference between "waste" and "fertiliser"** by structuring nutrient recycling to ensure professionalism and reliable product quality.

Kees Langeveld, ICL Fertilizers, reminded that **phosphorus recycling can be through recovery of high added-value products for industrial applications as well as recycling into fertilisers**. ICL is active in both directions, using sewage sludge incineration ash in fertiliser production and testing technology to recover P4 (white phosphorus). He noted that this conference has identified many regulatory obstacles and questions. Cooperation between EU Member States can help find realistic solutions. Contaminant limits, including in the new EU Fertilisers Regulation, must be based on risk assessment and not arbitrarily low, or recycling will be blocked.

Pascal Denoroy, INRA and **COMIFER**, emphasised the **need for dialogue between different stakeholders**, as initiated through this conference, including exchange between agronomic scientists and farmers and field tests to better use recycled nutrient products. In particular, long-term field trials are necessary for MAFOR products because of the complexity of interactions between different compounds in MAFOR, soil components and biology and crops.

In discussion, **Charlotte Berens, Véolia**, regretted the **probable disappearance of the public guarantee fund for risks related to sludge application** (*abolition* 2017 of TCA tax funding this). Participants underlined the need to anticipate accidental pollution and the current absence of a financial tool for polluted agricultural soils.

Conclusions

The conference demonstrated a **strong interest in France in recycled phosphorus products in agriculture**, with participants from a range of organisations and industries. France today recycles most of its organic residuals (MAFOR) back to agriculture. **Priorities today are: to maintain the current 75% of sewage sludge recycled to farmland** by addressing concerns about contaminants, and to **improve separate collection and valorisation of municipal organic waste, including food waste**.

France has strong competence and experience in quality standards for recycled products and a very structured regulatory system (NFU, AMM). This is important in developing the professional, reliable, quality recycled product sector wished by farmers, and also in ensuring safety for health, soil and the environment. However, this structured system also lacks flexibility to facilitate innovation and enable new products, especially in the field of waste valorisation which requires the coordinated action of three Ministries.

Development of the nutrient circular economy will be driven by French **policies** including the law on Energy and Green Growth, BioEconomy Strategy, as well as by EU policies (Circular Economy package, new Fertilisers Regulation, and phosphate rock on EU Critical Raw Materials List).

Specific regulatory issues were raised by the conference which should be addressed:

- **Guarantee fund for sludge application**, MAFOR contamination and polluted agricultural soils
- **Derogatory regimes** for temporary launch authorisation of new products, niche recycling products
- **Flexibility for funding** of manure recycling investments
- Clarification of producer responsibility and traceability

Concerning **scientific knowledge**, key needs identified are a better understanding of how organic recycled nutrient materials interact with soil, matrix of region – soil – crop fertilisation data for different MAFOR, valuation of the positive aspects of organic carbon input to soils, and long-term field trials (ten years plus).

A range of **concerns about contaminants in organic residual materials** were expressed. Both information and dialogue need to be developed, in particular organic contaminants in sewage sludge (e.g. pharmaceuticals) which are a relatively "new" concern and could pose a threat to France's currently high rate of sewage sludge recycling to farmland (nutrients, organic carbon).

This first French conference on phosphorus recycling in agriculture showed the **need for further dialogue between different Ministries, between science, farmers and industry, and with other societal stakeholders, in particular opening discussion with the agri-food industry**. This should address the implementation of the nutrient circular economy (regulation, economy, logistics, organisation) and also the societal aspects of acceptance of organic residual use in farming (contaminants, risk assessment, image of secondary products).

Conference, AgroParisTech, 11th April 2017 "Le phosphore recyclé en agriculture: gisements, produits, qualité, réglementation" (Recycled phosphorus in agriculture: secondary resources, products, quality, regulation), co-organised by COMIFER (French national committee for the study and development of rational fertilisation) and ESPP, with the patronage of the Ministry for Agriculture Food and Forestry. This summary will also be available in French at www.comifer.asso.fr

Resource efficiency in practice: improving farm nutrient management

The EU funded report "Resource efficiency in practice – closing mineral cycles" looked at farm nutrient management and best practices, based on case studies and with stakeholder dialogue in 8 different European regions. The final project documents are now (incompletely) published *www.mineral-cycles.eu*

The project objectives (see *tender*) were to identify the effects of intensive agriculture in nutrient saturated areas, the possibility of processing and transfer of manure to non nutrient saturated areas and to **identify processing techniques and possible options for increasing manure use efficiency on farms**. In fact, the final report includes only limited information on a few processing techniques (two page overview of liquid-solid separation, drying – pelletising, composting, anaerobic digestion, pages 90-91).

The project included a final conference (Brussels, 18th November 2014, including a presentation by the Netherlands Nutrient Platform) and four regional conferences in Southern and Eastern Ireland, Murcia (Spain - no proceedings for this conference), Lombardy (Italy), Wielkopolskie (Poland). Additional regions are studied in the project report are: Brittany (France), (Midtjylland Mid-Jutland (West Denmark), Weser-Ems (Northwest Germany), North Brabant (Southern Netherlands).

These eight nutrient surplus regions were identified from NUTS2 data (Eurostat, Nomenclature of Territorial Units for Statistics) for which a range of other data is presented (N and P application, surplus, NO_x, N_2O and ammonia emissions, aquatic nutrient pollution risk). Nutrient scarcity regions were also identified but not further studied: South-East France (Languedoc – PACA), Andalucia Spain, South Italy, Central Sweden, Umbria Italy.

The project final report (490 pages, plus translation of summary in French) is dated April 2016 (more than a year after the end of the project) and is *published* by the EU, but is not on the project website. The project deliverables were stated to include a "**database of solutions**"[1] and **"practical and region-specific guidance documents for the farming community"**[2] for eight European regions, but these seem not to be available.

The project report considers:

- impacts of agriculture on nutrient cycles and the impacts of nutrient losses on the environment and on human health
- possible solutions to address nutrient loss from livestock and from crop production (reducing sources, improving nutrient efficiency, controlling pathways)
- manure transfer: regulatory framework, market, transport, organic matter balance, animal health/hygiene
- identifies nutrient saturated and nutrient scarce areas in Europe
- presents the case studies of the 8 regions (see above)

The report concludes that "*A large panel of good practices exist and there is no ideal solution*". Certain **good agricultural practices are nonetheless**

proposed for in the documents for most of the 8 regions: improved fertilisation management plans, manure processing, improved manure application techniques.

Innovative practices cited as to be developed are: struvite precipitation, reuse of agricultural drainage water for irrigation and GIS-assisted precision fertilisation.

A **table of state of the art of good practices** is stated[3] to be publicly available in a separate excel file (not on report website: requested from *final-conference@mineral-cycles.eu* but not received). For 75 measures, this is stated to provide a qualitative assessment of expected benefits for the different environmental compartments, technical requirements, acceptability to farmers, costs, and profitability.

Local solutions, farmer and consumer information

The three regional conferences (proceedings not published for Spain conference) proposed different and specific actions, reflecting the range of different agricultural, economic and environmental contexts. All however emphasised that **policies and solutions need to be flexible to adapt to specific local situations**.

These regions also confirmed the need to improve outreach and information for farmers, including through research, demonstration farms, farmer advisory services, communication and dissemination. **Communications involving farmers with their own peers are identified as particularly effective**, including pilot farms, awards for innovative farmers, farmer ambassadors, dissemination through farmers' organisations and cooperatives.

Nutrient management measures will often only show environmental results after some years, and communications to farmers must explain this lag-time.

Facilitating farmer cooperation is important to enable knowledge sharing and joint investment in e.g. manure processing or precision nutrient management systems.

Information through the food industry value-chain to consumers is also identified as important, because dietary choices strongly impact nutrient use in farming, and also to involve the supply chain. Initiatives such as PEF (Product Environmental Footprint) were cited, but with concerns about the challenges of application to agricultural products.

Costs of nutrient losses

Real costs of agricultural nutrient losses in Brittany are estimated in the report to include: €1 million/year for removal of algae from beaches, € 70-100 million/year revenue losses for coastal tourism, €120-360 million/year for drinking water treatment (nitrates). Hypothetical clean-up costs for groundwater (nitrates) and surface and coastal waters (eutrophication) are estimated as nearly € 500 billion and € 50 billion.

A particular issue identified in Brittany is the use of manure on maize (over 30% of regional arable land) because maize is tolerant to over-fertilisation, so allowing excessive manure application.

Measures identified to address nutrient pollution in Brittany include: controlling geographical distribution of livestock, adapting feeding strategies, processing manure to reduce nutrient content, improving nutrient fertilisation management plans, converting arable to grassland, covering slurry tanks to reduce ammonia emissions, installing scrapers in piggeries, rotating grazing in pastures to reduce manure application, taking weather into account in manure spreading and use of grass strips along hedgerows.

For North Brabant, The Netherlands, an improvement of water quality is estimated to potentially provide nearly € 600 000 revenue per year for tourism and recreation and increase housing prices by 2 – 7 %.

For Ireland, an increase in efficiency of agricultural inputs would save € 55 million per year.

In Weser-Ems, Germany, drinking water consumers currently pay over € 4 million/year in charges on water bills which are transferred to farmers to pay for actions to reduce nitrate pollution. **Costs to society of atmospheric nitrogen emissions are estimated at 22€/kg N-NH_3 and 32€/kgN-NO_x for medical costs and wage and productivity losses resulting from the formation of atmospheric particulates**.

Manure transfer

Obstacles to **manure transfer from nutrient surplus regions to arable areas** are identified as: costs for storage, transport, necessity – and so cost – of solid-liquid separation and other processing before transport (to reduce transport volumes and costs), regulatory complexity, e.g. European Waste Shipment Regulation 1013/2006 and Animal By Products Regulations 1069/2009/EC and 1774/2002/EC.

Maps of estimated costs for manure transport and processing are provided (calculated by LEI Wageningen UR, based on FADN 2010, Lyngsø Foged, et al., 2011, Schroder, et al., 2010).

The interest of transferring organic matter in manure to regions with low soil organic matter are discussed, and hygiene issues relating to manure sanisation and transport are summarised.

EU and Member State policies: Rural Development Funding

Stakeholders from the different regions emphasised the **importance of EU agricultural and environmental policies**, and their national or regional implementation, including the financial support framework and incentives for farmers.

As stated in the Lombardy meeting report: "*The use of public subsidies remains an important way forward, considering the availability of resources resulting from the RDP. These resources should, however, be carefully and precisely directed according to clear policies and directly applicable and development plans that are stable and can be implemented over long periods of time … The real innovation in the regulatory landscape would be to go from schemes with passive and coercive rules (fixed application limits, various prohibitions) to active rules that actually reward the introduction of innovation, especially operational innovation. This incentive would make investment in innovation economically viable*."

Andrea Vettori, DG Environment, underlined "*the need for flexibility in policy*" to respond to local contexts but also the "missed opportunities, such as the objectives in RDP (Rural Development Plans) being set too low"

Regional stakeholders considered that **a combination of regulation and voluntary tools can be effective,** and should include actions coordinated at the catchment level. Farmer information is important to explain the environmental objectives of regulations but also how nutrient efficiency can save money. Locally targeted financial support should encourage good management practices such as buffer zones or cover crops, where these are appropriate and managed.

Good Management Practices and nutrient measures

The following **measures to reduce nutrient pollution** are identified for the different regions studied:

- testing of forage for animal feed, improving animal feed nutrient management
- improving manure storage: impermeable ground surface, increasing height of manure heaps, cooling of slurry, coverage of slurry tanks
- conservation and precision farming techniques, timing and amount of application of manure, improving fertilisation management plans
- manure application techniques and incorporation of manure to decrease ammonia emissions, avoid leaching and run-off, improve mineral uptake
- use of hydrometers in slurry tankers to monitor what is spread,
- soil analysis to support nutrient management planning
- organic farming
- nutrient buffer strips, catch/cover crops and perennial crops
- improving drainage, enabling recovery of nutrient-polluted drainage water
- improving irrigation systems
- mineral fertilisers with nitrification inhibitors
- low impact tilling techniques, perpendicular ploughing
- increase grazing duration and rotational grazing
- processing of manure, including composting and anaerobic digestion, nutrient recovery and recycling from manure and from agricultural drainage ditches, and transfer of recovered nutrients to regions without nutrient surpluses
- agro-forestry to improve nutrient uptake and provide shelter for grass, biodiversity and mitigate flooding

1 = Bio Deloitte project manager in final conference proceedings. 2 = project website. 3 = K. Muehmel BioDeloitte in project final conference presentation. EU Commission (DG ENVI) funded project "Resource efficiency in practice – closing mineral cycles", 2013-2014, realised by BioDeloitte, Ecologic Institute, AMEC Environment & Infrastructure UK, Technical University of Denmark, the University of Milan and Wageningen University & Research Centre, Agricultural Economics Institute (LEI). Project website with presentations and proceedings of the four regional conferences (no proceedings for Spain conference) and for the final conference www.mineral-cycles.eu/ *Project final report* https://publications.europa.eu/en/publication-detail/-/publication/c4e6e51f-18cc-11e6-ba9a-01aa75ed71a1/language-en

World Circular Economy Forum (WCEF)

The first World Circular Economy Forum, 2017, brought together 1 500 participants from across the world, for 17 plenary and parallel sessions showcasing circular economy solutions for business, cities and finance. It included three days of discussions, networking, workshops, side events and business excursions.

The Forum was opened by **Mikko Kosonen, President of the Finnish Innovation Fund SITRA** (SITRA was the main organizer of the event), Kimmo Tiilikainen, Finnish Minister for Housing, Energy and the Environment, **Matti Vanhanen, Finnish MP** and **Jan Vapaavuori, Vice President of the Finnish Investment Bank**.

Janez Potočnik, Co-chair of the UNEP International Resources Panel opened the first plenary with a *presentation* titled "Global use of natural resources – in crisis or not?", followed by **Achim Steiner, Administrator of the United Nationals Development Programme**, *talking* about circular economy as a means to achieve the UN Sustainable Development Goals and reduce poverty and **Mikko Kosonen** *presenting* "Circular Economy total transformation – can it be achieved?" The plenary was completed by a panel discussion with high level speakers including Tadahiko Ito, **Japanese Minister of Environment, Sergei Ivanov, representative of the Russian President, Alice Kaudia, Environment Secretary of Kenya**, Janez Potočnik, Achim Steiner and **UNEP Deputy Executive Director Ibrahim Thiaw**.

The first plenary and most parallel sessions focused on **the need for a circular economy in order to end the excessive use of natural resources**. Some African panellists, however, criticised some European practices sometimes presented as circular economy actions: exporting food that is not eaten by Europeans and second hand garments to African markets undermine local economic structures and contribute to poverty rather than abating it. Even worse is the illegal but widespread practice of shipping end-of-life electronic devices to Africa for "recycling", which in reality involves use of toxic chemicals and in appropriate handling and processes which compromise human health and the environment.

In other plenary sessions "**Circular Business Leaders**" and "**Circular Cities**" were presented, exhibiting some remarkable result, such as Vancouver's *approach* to a circular city economy). However, not all approaches were leading edge solutions, such as the efforts of New York to avoid disposal of the waste in distant landfills. Parallel sessions included bio-based economy, SMEs, challenge prizes and awards, sustainable consumption and production, forest based bio-economy, transformation to circular business models, circular value chains, branding circularity for consumer value, financing the circular economy and future technologies for the circular economy. At least one session dealt with economic research on the circular economy, where **Paul Ekins** (UCL) *presented* economic models developed during the Joint EU R&D Projects **POLFREE** and **DYNAMIX** (see SCOPE Newsletter *n°120*) and showing that business as usual not being a serious option due to its disastrous consequences.

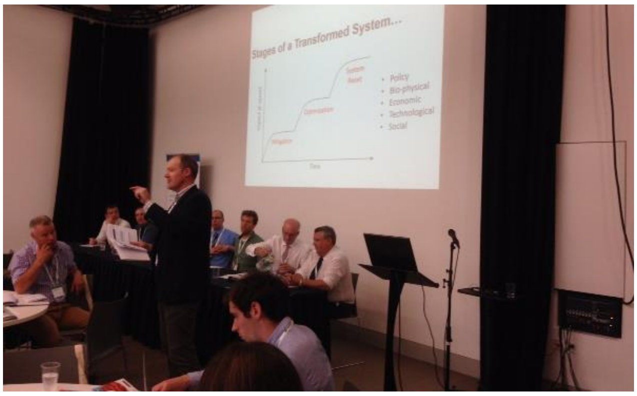
With its high profile international speakers and the large number of international delegates present, the FORUM was a distinct success. **Mari Pantsar from Sitra** presented the plan to co-organize a CE Forum in another city and to bring a large CE Forum back to Helsinki in 2019.

Article provided by Ludwig Hermann, Outotec. First World Circular Economy Forum, Helsinki, 5-7 June 2017
www.sitra.fi/en/projects/world-circular-economy-forum-2017

All Ireland phosphorus workshop

The All Ireland Phosphorus Sustainability Workshop and Microbial Resources for Agriculture and Food Security Conference, 21-23rd of June 2017, Belfast, Northern Ireland brought together over 150 delegates, speakers and exhibitors.

The events were jointly organised by the School of Biological Sciences and Institute for Global Food Security at Queen's University Belfast (Katrina Macintosh, Jason Chin and John McGrath), and National University of Ireland Galway (Vincent O'Flaherty), in partnership with the Environmental Protection Agency and Microbiology Society.



Phosphorus Sustainability Workshop

The one-day workshop on Irish phosphorus sustainability brought together regulators, researchers, industry, academics and stakeholders to discuss needed **solutions for agricultural sustainability and food security** especially in the context of phosphorus (P) management in the island of Ireland.

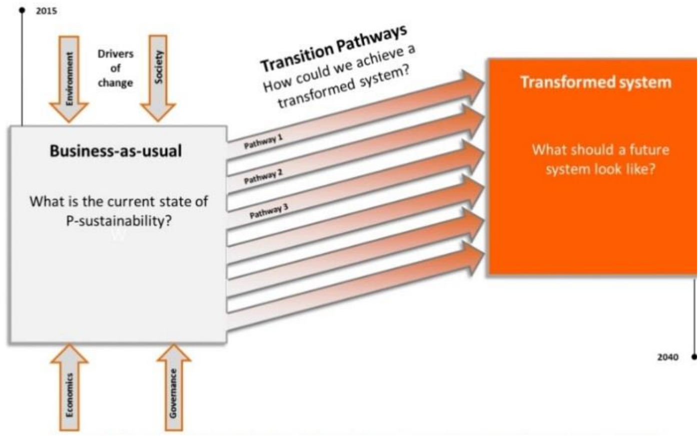
Through keynotes, panel member discussions, and delegate breakout groups the workshop:

- discussed **scenarios** for effective P management,
- increased **awareness** of existing P recycling technologies and envisioned their implementation within the agri-food and waste treatment sector
- developed a **market understanding** for technological/management gaps requiring further research.

Objectives of the workshop were to:

- Identify the key issues on P management on the Island of Ireland
- Develop a conceptual model for transformational change for P sustainability on the Island of Ireland
- Consider the establishment of an Island of Ireland Nutrient Platform

The workshop was facilitated by **Dana Cordell** and **Brent Jacobs** from the **University of Technology, Sydney**, Australia. The **transformation change model** was used to capture information arising from the workshop by asking: What is current, business-as-usual practice – what is current status in terms of P? What would a transformed system be – what would a future system look like? What are the transition pathways from current to optimal practice – how could we achieve a transformed system? What are the barriers/constraints/enablers/drivers of change? Information obtained from the workshop will be synthesised to produce a model for P transformational change on the Island of Ireland.



Conceptual model of transformative change (adapted from Jacobs et al. 2016)

Sessions at the workshop were convened on: Regulatory perspectives on P management, chaired by **Richard McDowell** from **AgResearch and Lincoln University**, New Zealand; Perspectives on P recovery, recycling and reuse, chaired by **Paul Butler** from **Enterprise Ireland**; Future directions for P sustainability, chaired by **Phil Haygarth**, **University of Lancaster**, UK

Keynote talks were delivered by **Kimo van Dijk**, from the **European Sustainable Phosphorus Platform (ESPP)**, who presented on the challenges and opportunities of P stewardship in Ireland within an EU regulatory perspective; **John Gilliland**, from **Devenish Nutrition**, who detailed how the Northern Ireland Sustainable Land Management Strategy could be used to deliver better phosphate management in Northern Ireland; and **Christian Kabbe**, from **Kompetenzzentrum Wasser Berlin** and the **German Phosphorus Platform**, who updated delegates on the circular economy in relation to challenges and opportunities for P recovery and recycling in Europe.

There were also short presentations from representatives of both Irish, Northern Irish and UK government bodies, water utilities, departments of agriculture, and industry: **Raymond Smith**, **Environmental Protection Agency** (‘*P reduction in rivers and lakes – progress made and future challenges*’); **Kieran McCavana, Northern Ireland Environment Agency’s Water Management Unit** (‘*Agricultural P management in Northern Ireland – an environmental problem or a potential opportunity?*’); **Thomas Gardiner, Northern Ireland Water** (‘*P removal from wastewater in Northern Ireland*’); **Ted O’Reilly, Irish Water** (‘*P removal in a regulated environment*’); **Alan Morrow, Department of Agriculture, Environment and Rural Affairs** (‘*P – a little goes a long way or does it?*’); **Patricia Arcenegui, Veolia** (‘*Business opportunities for Veolia’s recycled fertilisers made from bio-ashes*’); **Andrea Gysin, Ostara Nutrient Recovery Technologies** (*Experiences of recovering high value P fertiliser from wastewater*’); **Fiona Brennan, Teagasc Johnstown Castle** (‘*Maintaining P supply for plants in Irish soils*’); **Gabriel Kelly, Dairygold Co-**

Operative Society Limited (‘*Perspectives from the dairy processing industry*’) and **Barbara Bremner, University of the Highlands and Island** (‘*Phos4You – addressing the P challenge through transnational cooperation’).*

Microbial Resources for Agriculture and Food Security Conference

This conference was an Irish Division meeting of the Microbiology Society. As micro-organisms play a pivotal role not only in P cycling, but across the agri-food sector, the conference focused on their diverse roles in agriculture, from increasing farming efficiency to safe environmental management, and the production of value added products from agri-food and bio-based waste streams. Keynote talks encompassed biogeochemistry, microbiology, crop science, modelling, and process engineering. The meeting promoted a multi-disciplinary understanding of new approaches and biotechnological possibilities to **improve our ability to harness microbial processes, thereby providing more efficient and sustainable agri-food systems with better environmental stewardship**.

The first session examined “*Nutrients in the environment with a focus on agricultural systems*”, where **Dana Cordell** and **Brent Jacobs** presented on adapting to P vulnerability for a food secure future; **Phil Haygarth, Lancaster University**, UK, presented on ‘*P in the land-water continuum: are we ready for the future?*’, highlighting the implications and complexities of P and organic P loss from agricultural systems to receiving rivers, lakes and estuaries; **Richard McDowell, AgResearch & Lincoln University**, discussed ‘*Why P concentrations in water have decreased, while agricultural production in New Zealand has increased*’ and noted that the implementation of good management practices through voluntary or regulatory schemes was integral to declining P concentrations. Finally, **Lionel Dupuy**, from **The James Hutton Institute**, UK, concluded session one by talking on ‘*New ways to look at root-microbe interactions*’, noting the importance of roots and their interactions with the soil and micro-organisms in terms of nutrient uptake and disease transmission, and highlighted new approaches developed for *in situ* analysis.

In session two, “*Microbial ecosystems and nutrient cycling*”, **Kari Dunfield, University of Guelph**, Canada, discussed the ‘*Impact of agricultural practices on the diversity and activity of key functional groups of microorganisms in the soil nitrogen (N) and P cycles’*; **Tim Lenton, University of Exeter**, UK, gave a thought provoking talk on ‘*The fundamental role of microbial nutrient cycling in the Earth system*’ in relation to the microbial biosphere and its role in establishing and regulating global nutrient, carbon and oxygen cycles; while **Penny Hirsch, Rothamsted Research**, UK, discussed the ‘*Role of soil microbiome in the nitrogen cycle’*.

Keynote talks for the final session on “*Harnessing microbial processes within the agri-food sector*”, were given by **Anna Schnürer**, from **University of Agricultural Sciences**, Sweden, who discussed the ‘*Microbial management for optimised biogas production from organic wastes*’; and **Jason Chin, Queen’s University Belfast**, Northern Ireland and **Fabiana Paula, National University of Ireland Galway** who jointly discussed their Science Foundation Ireland – Department for the Economy funded project ‘*P cycling and capture by methanogenic archaea’*, examining the microbial communities of anaerobic digesters and polyphosphate production with particular focus on *Methanosarcina mazei*.

Other papers at the conference included “*Revisiting the soil microbial organic P cycle: Discovery of novel mechanisms to mobilise P in Flavobacteria spp.*” by **Ian Lidbury, University of Warwick**, UK; “*Impact of drainage and P status on grassland microbial communities*” by **Jessica Graça, Teagasc**, Ireland; “*Recycling P from sewage sludge ash with the help of Phosphate Solubilising Micro-organisms*” by **Nelly Raymond, Copenhagen University**, Denmark; “*Soil microbes as facilitators in restoration of post-mining substrates*” from **Deepak Kumaresan, Queen’s University Belfast**, Northern Ireland; “*Pathogen survival in agriculture-based anaerobic digestion compared with stored slurry*” by **Stephen Nolan, National University of Ireland Galway**, Ireland; “*Soil microbial community responses to compounded soil management and climatic disturbances*” from **Camilla Thorn, National University of Ireland Galway**, Ireland; and “*Optimising enrichment culture* *for isolation of Clostridium difficile from animal and environmental samples*" from **Mairead Connor, Queen's University Belfast**, Northern Ireland.

The prize for the best student presentation and Young Irish Microbiologist of the Year was awarded to **Mairead Connor, Queen's University Belfast** who will go on to represent the Irish Division of the Microbiology Society at the Sir Howard Dalton Young Microbiologist of the Year competition later in September. The first prize poster was awarded to **Kate Randall, University College Dublin**, and second prize to **Corine Nzeteu, National University of Ireland Galway**.

Overall the conference and workshop helped to **develop ideas and identify challenges to Irish phosphorus sustainability**, while also generating much discussion around the latest research in the field. Outworking's from this workshop and future follow up meetings will form a basis for defining a possible all Ireland nutrient platform or network, which will aim to address the challenges identified by delegates.

The organising committee would like to thank the keynote speakers, panel members, session chairs, table facilitators, exhibitors and sponsors. Sponsors included the Environmental Protection Agency, Science Foundation Ireland, Devenish Nutrition, Ostara and Athena SWAN at the School of Biological Sciences at Queen's University Belfast. Exhibitors included Premier Scientific, Sartorius, WVR, Constant Systems, Mason Technology, Davidson and Hardy and Ostara. Thanks also to the Metropolitan Arts Centre www.themaclive.com *and for their help in hosting this event and NATIVE™ by Yellow Door (*http://yellowdoordeli.co.uk/native*) for catering.*

Microbial Resources for Agriculture and Food Security and All Island Phosphorus Sustainability Workshop,21-23rd of June 2016, Belfast, Northern Ireland
www.microbiologysociety.org/event/society-events-and-meetings/focused-meeting-2017-irish-division-microbial-resources-for-agricultural-and-food-security *and* www.phosphorus.ie Programme book is available online.

Follow on Twitter @Phosphorus_ie @MicrobioSoc *#AgriFoodSec17*

Summary prepared by Katrina Macintosh and Jason Chin, Queen's University Belfast.

Phosphorus recovery and recycling in Japan

Anders Nättorp, FHNW and ESPP Board, reports on a study visit to Japan, organised by the Phosphorus Recycling Promotion Council of Japan (PRPCJ) to discuss P-REX results and ESPP activities, with visits to two sites implementing recovery technologies unique to Japan.

The Japanese Ministry of Land, Infrastructure Transport and Tourism (MLITT) is conscious that the phosphorus in wastewater is a resource, but until now recycling was not a priority. Consequently phosphorus in sludge is only used for a small part through some application of sludge to non-agricultural lands. Mostly the sludge is incinerated and the ash is used for cement production or other construction purposes. Part of the sludge ash is also landfilled.

Recycling is implemented full scale by five sewage plants in Japan: three that perform struvite precipitation and by two plants which apply the alkaline ash leaching process presented below.

PRPCJ members were curious to **learn more about European experiences** such as all the technologies available as shown by the P-REX project (*www.p-rex.eu*), the circular economy package and the opening up of the fertiliser regulation for recovered materials *(See summary ESPP-meeting June 2016)* and the resulting developments on the ground, for example the new production line for DCP from ash by Ecophos in Dunkerque or the FP7 Recophos process being piloted by ICL for future implementation (*Link Ecophos Dunkerque*; ICL see SCOPE Newsletter *n°120*). The very fruitful discussions with industry representatives and university professors revolved around the reasons for the relatively positive political development in Europe compared to Japan; fertiliser quality and market; phosphorus and P4 supply security; the differences in wastewater treatment and sewage sludge disposal between Europe and Japan.

Alkaline leaching of sewage sludge ash in Gifu

The Gifu city has four wastewater plants which treat sewage from 284 000 inhabitants. The sludge from these plants is incinerated in two sludge mono-incineration plants, generating around 710 tonnes of ash per year. In the past, the municipality used the ash to produce bricks for use in public construction works. Decreasing demand for bricks and high landfill costs for ash led to the search for alternative solutions.

The development of a **new process for treatment of ash by alkaline leaching** started in 2003 with funding from MLITT and collaboration between private sector (Metawater Co. Ltd, *www.metawater.co.jp/eng*) and the public sector (municipality of Gifu).

The process consists in leaching of the sludge ash by dilute NaOH (for 5-30 minutes at 50-70 °C), filtering, precipitation by $Ca(OH)_2$ (for 6 hours at 20-50°C) and separation of the product by sedimentation and centrifugation, followed by drying to 20% DM. The precipitation liquor is recirculated.

The initial phosphorus content of the ash (30-35% P_2O_5) is lowered by around 30% (to approx. 22% P_2O_5), that is around 30% of P is recovered. Heavy metals leaching out of the ash into the phosphate product is lower with the alkaline leaching than with acid leaching, and is limited by keeping the P-recovery rate down to around 30%.

The leached ash is washed twice with water and then with an acid poly-ferric sulfate solution to immobilize the remaining metals. The leached ash now weighs slightly more than the initial ash weight before treatment (c. 750 tonnes/year wet weight), and its humidity has now increased to 30% compared to <0.5% originally. The leached ash is used as construction material or as soil amendment for tree planting (it still contains significant phosphorus).

Around 230 t/y of calcium phosphate (calcium hydroxyapatite) is produced (containing 27 t P/y). This has 29% citric acid phosphate solubility. It is well below the limits in the Japanese fertiliser control act for heavy metal limits (by factors between 3 and 100). Around **90% of the product is sold to the fertiliser industry** and the remainder is granulated to standard size and sold directly for use as fertiliser to JA ZEN-NO (National Federation of Agricultural Cooperative Associations *www.zennoh.or.jp/about/english/index.html*) at 20 000 JPY/t, i.e. around 70% of the price of conventional fertiliser.

After successful lab experiments piloting and product registration, the full scale ash leaching plant was brought into operation in Gifu in 2010. **The overall ash treatment cost is lower than the previous brick production and represents less than 3% percent of the total wastewater treatment cost**.

Another slightly smaller full scale plant using the same alkaline ash leaching process is operated in the municipality of Tottori.

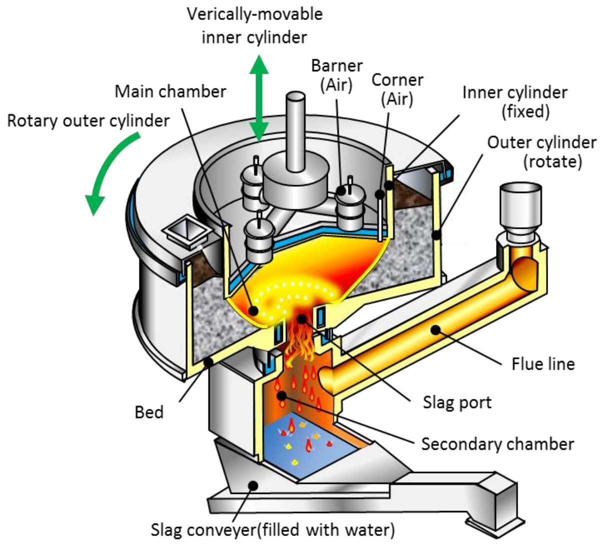
Part of the phosphorus recovered in the Gifu plant is granulated and sold directly as fertiliser by JA ZEN-NO.

Kubota sludge furnace process

The Kubota Corporation with over 33 000 employees provides piping, agricultural machines, construction machines and equipment also delivers melting furnace technology. **More than 30 furnaces have been constructed the last 40 years in Japan. Most of them are still in operation for the treatment of sewage sludge, ash, industrial and hazardous waste and gasification of pyrolysis residues.** We visited one of the municipalities using Kubota furnaces for sewage sludge disposal since several decades. Kubota services operates the furnace, a common setup for smaller municipalities.

Dewatered sewage sludge is dried to 80% dry matter in order to have a self-sustaining incineration. In the furnace, dried sewage sludge is pushed from the circumference of the circular reactor towards its centre. As it approaches the centre, the material gradually increases in temperature and decreases in volume. It burns at the surface, forming a melt that continuously flows through a contraction into a lower chamber where the flue gas is diverted to the side and the melted material falls freely into a water bath. The burning zone has a temperature of about 1300°C and the lower chamber is above 900°C to avoid dioxin formation. The flue gases are led through boilers which recover energy for sludge drying and then through exhaust treatment. The plant capacity depends on the diameter of the oven, which can range from 1.2 m to 10 m (equivalent to 35 000 t dry matter per year).

Up to now slag has been used in the construction sector, for public works backfilling. The last years Kubota has developed the process to enable phosphate recovery. Through addition of iron oxide (Fe_2O_3) and careful control of the oxygen concentration the phosphorus can be kept in the melt whereas the more volatile heavy metals (Pb, Zn, Cd, Cu etc.) are removed in gaseous form. Nickel, part of the copper and some other metals remain in the phosphoric slag as metallic droplets. A further mechanical separation of these droplets is considered by Kubota as feasible.



Schematic Diagram of Kubota Melting Furnace

In order to increase the plant availability of phosphorus in the recovered slag, calcium hydroxide is added and the melt is rapidly cooled with water. Thus a slag with >90% citric acid solubility of phosphorus and a P-recovery rate of over 90% can be achieved. **Pot tests on rice at soil pH 5.5 show a fertiliser efficiency of 97% relative to single super phosphate.**

The energy balance is also being improved by recovery of heat from the oven itself. Through this measure it is projected to be able to deliver an oven processing dewatered sludge without additional fuel (today 20l/t of fuel oil sludge treated).

It is estimated that sludge disposal costs in the melting oven are approximately 20% higher than mono-incineration. However, the value of the phosphorus in the slag is estimated to be equivalent to that in phosphate rock (based on rock prices for import into Japan), more than enough to make up the higher cost. Kubota is currently looking for interested partners and potential clients to implement this phosphorus recovery process.

Report by Anders Nättorp, FHNW – University of Applied Sciences and Arts Northwest Switzerland.

With thanks to Prof. Hisao Ohtake, Waseda Univeryity and Fumiki Hosho, KUBOTA Corporation, for help in preparing this summary.

Agenda:

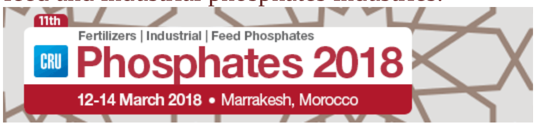
Sustainable Phosphorus Webinar #3: Extreme Climate, Extreme Phosphorus, 16 November 2017, Online *Website*

ManuREsource 2017 - International conference on manure management and valorisation
27 - 28 November 2017, Eindhoven, Netherlands - *Website*
Including, with ESPP

- Policy round table on processed manure in the **Nitrates Directive** – specific registration necessary *Website*
- One-to-one meetings with *Newtrient* (see p23 of this Newsletter) to extend the **catalogue of manure processing technologies and suppliers** to Europe

ESPP stakeholder meeting Recycled nutrients in organic farming, 12 December 2017, Brussels, Belgium - *Registration*
In collaboration with IFOAM, European stakeholder meeting on potentials and challenges for use of recycled nutrient products in organic farming

Phosphates 2018 conference
12 - 14 March 2018, Marrakesh, Morocco - *Website*
Gathering for decision-makers representing the fertiliser, feed and industrial phosphates industries.



SAVE THE DATE - 3rd European Sustainable Phosphorus Conference (ESPC3)
11 - 12 June 2018, Helsinki, Finland

6th Sustainable Phosphorus Summit (SPS2018)
20 - 22 August 2018, Brasilia, Brazil - *Website*
For the first time, the Summit will be held in Latin America, enabling a spotlight on the Tropics, where phosphorus sustainability is a big concern

Full events listing online at
www.phosphorusplatform.eu/events/upcoming-events

Stay informed through ESPP:

Subscribe to our newsletters & channels
SCOPE: ***www.phosphorusplatform.eu/SCOPEnewsletter***
eNews: ***www.phosphorusplatform.eu/eNews***
Twitter: ***@phosphorusfacts***
Slideshare: ***www.slideshare.net/NutrientPlatform***
Website: ***www.phosphorusplatform.eu***